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In-House Report
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WIDEBAND S BAND TRANSMITTER

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This report documents the in-house design and construction of two high power radar transmitters for the RADC Surveillance Laboratory. The first transmitter is an S band, 180 KW, 6% duty one which has been added to the existing vertical channel transmitter of the S band tracking radar to provide horizontal polarization coverage. The second is a 180 KW, 2% duty unit which powers the C band Advanced Mainbeam ECCM antenna.

This report covers the S band transmitter and comprises maintenance, operation, design philosophy, and theory of operation, as well as being expository of novel technologies used and recommendations for further research.

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1. INTRODUCTION

1.1 BACKGROUND

In 1978, an S band transmitter was built by RCA Corporation under contract F30602-78-C-0122, titled "Wideband Amplifier, P/O Digitally Coded Radar". After use by the DCR program (Digitally Coded Radar, a predecessor of the Advanced Tactical Radar and Advanced Tactical Surveillance Radar), it was incorporated into the Surveillance Laboratory to provide the RF power for an S band tracking radar to complement the L band search radar.

Dual polarization of the radar antenna was desired. To use the transmitter to power two polarizations, a ferromagnetic polarizer was considered. This would have several disadvantages: it would have almost 3 dB insertion loss, it would be very costly ($500K), and switching time would not allow rapid polarization changes (i.e., pulse to pulse).

It was decided that a second transmitter would be built instead, with a low power polarizer feeding both transmitters. The advantages of this approach are a fourfold increase in power, fast switching time between polarizations, and redundancy if a single polarization is desired. The two transmitters are shown at the 30 foot level on the tower in fig. 1-1.

WBA 1 in the documentation refers to the RCA unit which normally feeds the vertical channel of the antenna. WBA 2 is the newer RADC built transmitter which feeds the horizontal. A 90 degree hybrid waveguide section was also fabricated as part of this program to convert the output of each transmitter into circular polarization in the sense opposite the other transmitter.

1.2 SCOPE OF THIS PROJECT

This transmitter is not a copy of the first; a completely new design was done. The physical layout and placement of controls is similar, however, to avoid operator confusion. To reduce problems of phase and amplitude tracking between the two transmitters, both were operated from the two high voltage supplies in WBA 1. This made effective interfacing a primary requirement.

WBA 1 was experimental in nature, and advanced technology in the areas of lightweight inverter power supplies and high time-bandwidth power amplification. WBA 2 was designed primarily to be a useful research tool, but it also served as a test bed for evaluation of new technologies, such as:

1. Short haul Fiber optics for high isolation
2. Digital low power Schottky logic for interlocks
3. Power field effect transistors for high speed, high voltage pulse switching and amplification.

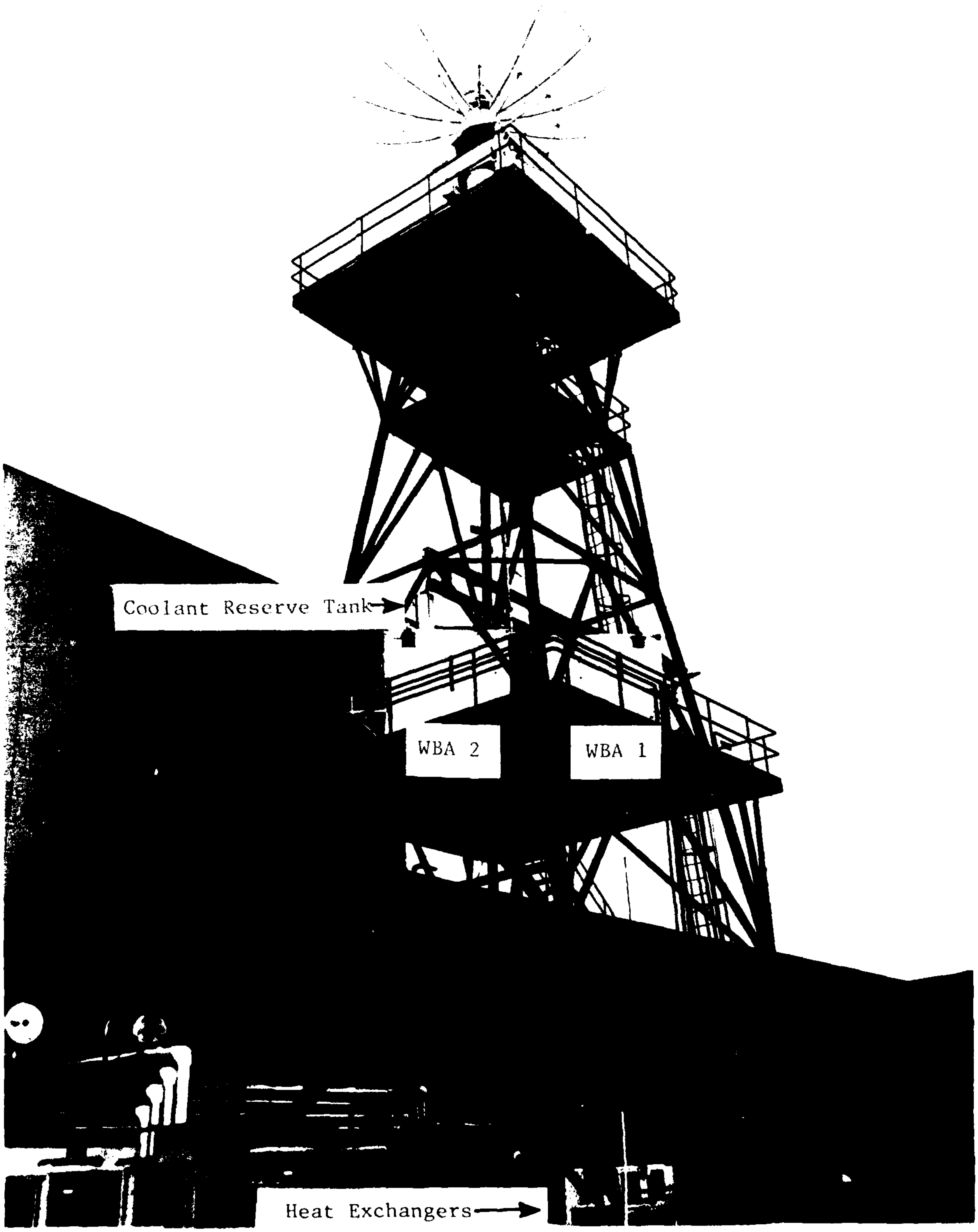


Fig. 1-1. S Band transmitters on tower

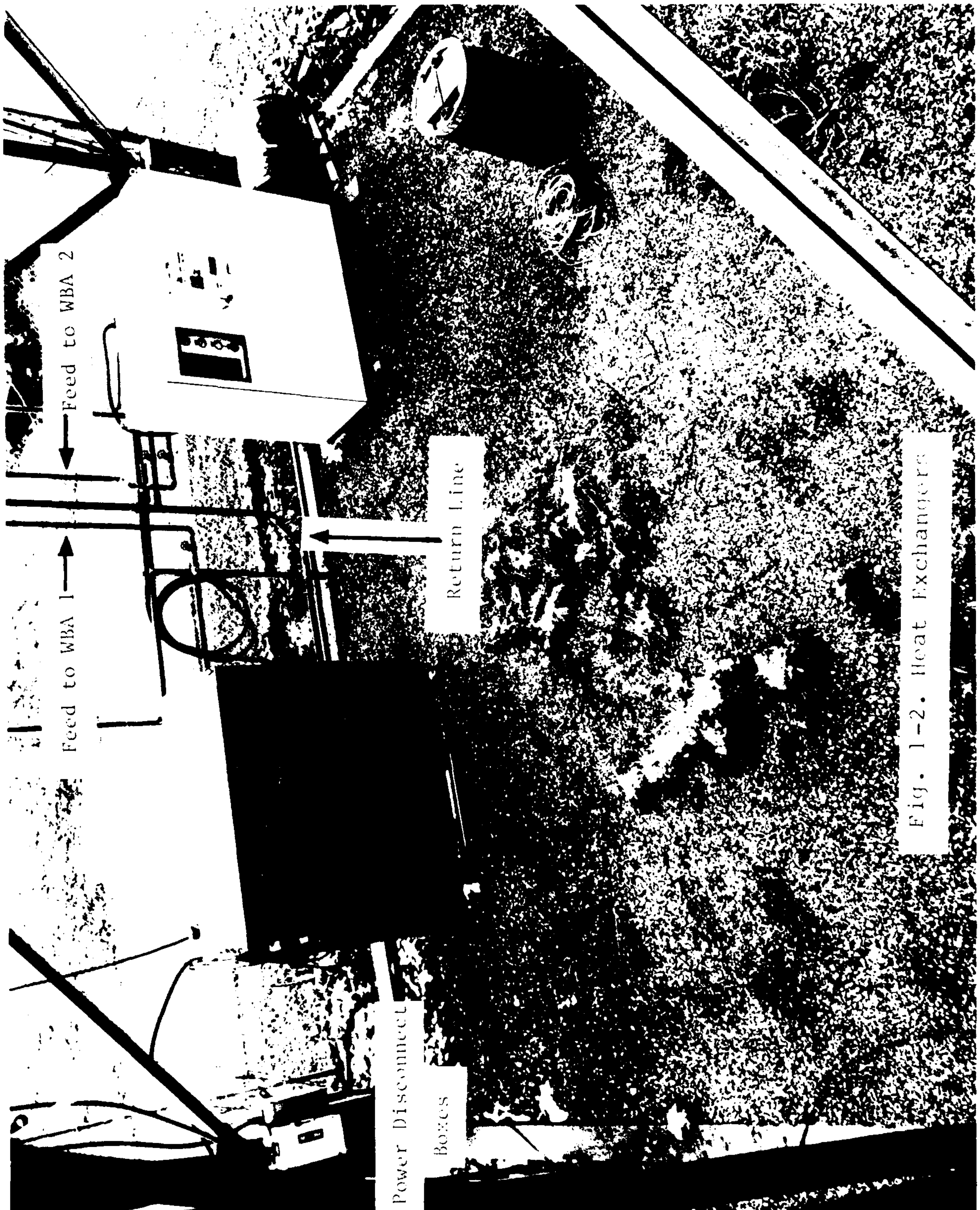


Fig. 1-2. Heat Exchangers

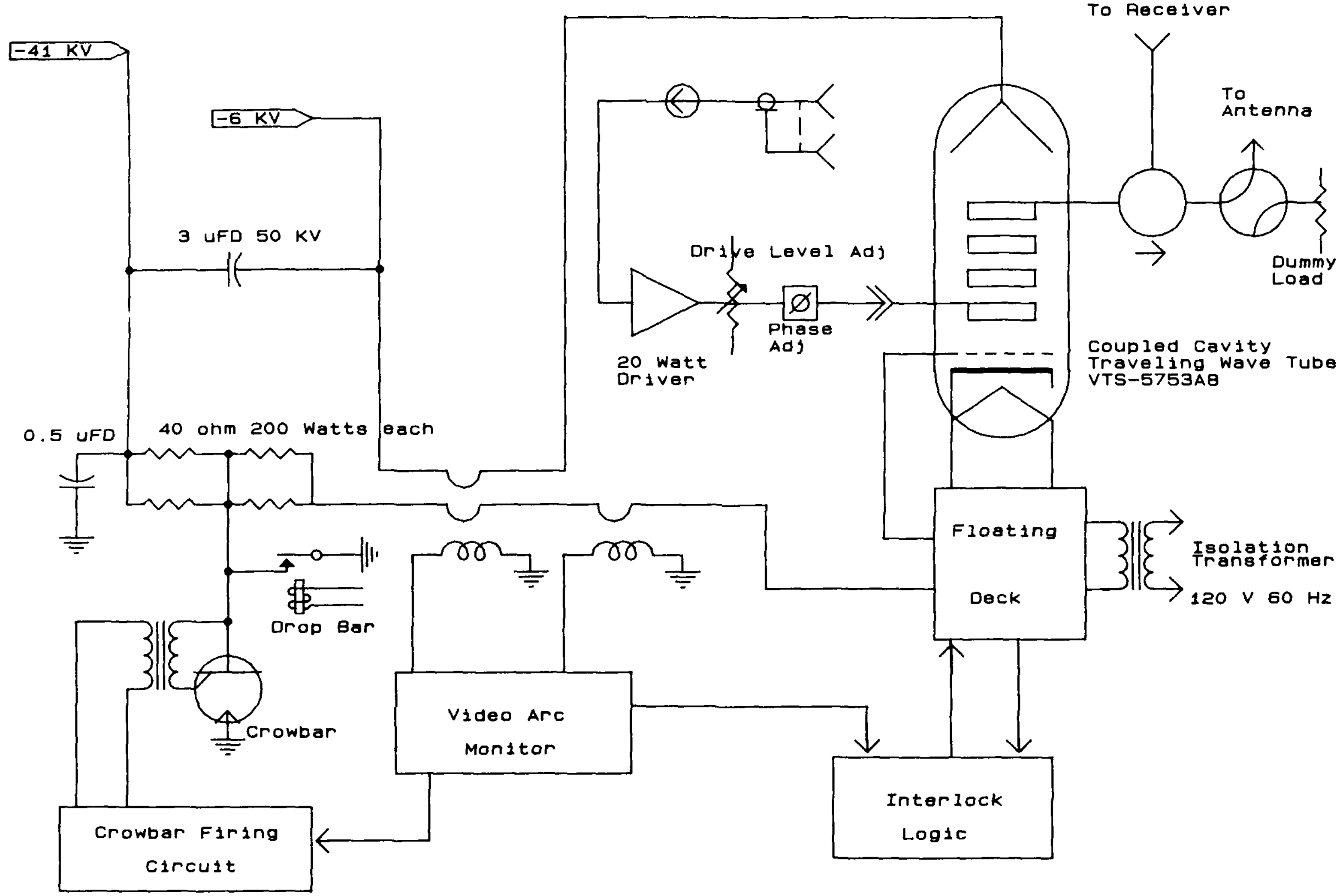


Fig. 1-3. Transmitter Block Diagram

Improvements were also made to the first transmitter to interface it with the second, to expand its versatility, to correct design flaws, and to update the technologies used.

Results of this work are described in the following parts of this report. Refer to the table of contents for specific topics.

1.3 BLOCK DIAGRAM DESCRIPTION

Refer to fig. 1-3. Although the transmitter is simply a one-stage amplifier, a traveling wave tube is a complicated device which is expected to amplify the exciter power 40 dB with good signal fidelity. The other parts of the transmitter supply the tube with proper DC and pulse voltages, cooling, and protection.

The video arc monitor continuously reads the collector and cathode currents and responds within 100 nanoseconds to levels above the set point. The tube could be permanently damaged if an arc was maintained between the cathode, at -41 KV, and the body of the tube at ground. Smaller levels of overcurrent could occur if the magnet solenoid on the tube lost its focusing ability, and the monitor detects these also.

The floating deck, or grid pulser, floats at the cathode potential. It must supply 120 watts of heater power to the tube, carefully current controlled during warmup. It receives a trigger pulse from the Surveillance Lab and amplifies it to a 1,100 volt swing grid drive signal which controls the tube. It supplies a continuous signal to the interlock logic when normal conditions are sensed and shuts off the high voltage in less than 500 nanoseconds in case of detection of abnormality in the cathode end of the tube.

The electronic crowbar diverts energy from the tube much faster than the drop bar (1 us). The resistors in the high voltage circuit limit the instantaneous surge through the tube to non-damaging levels until the logic fires the crowbar. Also, they assure damping in the crowbar circuit; if the Q of the discharge circuit was high enough to reverse the voltage swing across the crowbar, it would commutate, allowing damaging reapplication of voltage to the tube.

The RF components in the driver circuit allow the phase and amplitude of the transmitter to be varied as desired. Approximately 5 watts of driver power is required at the TWT input. The circulator at the output of the TWT protects the tube and channels receive signals into the radar receiver. The waveguide switch allows off-air testing at full load.

Not shown in the block diagram is the heat exchanger/filter which removes up to 75 KW of heat from the tube.

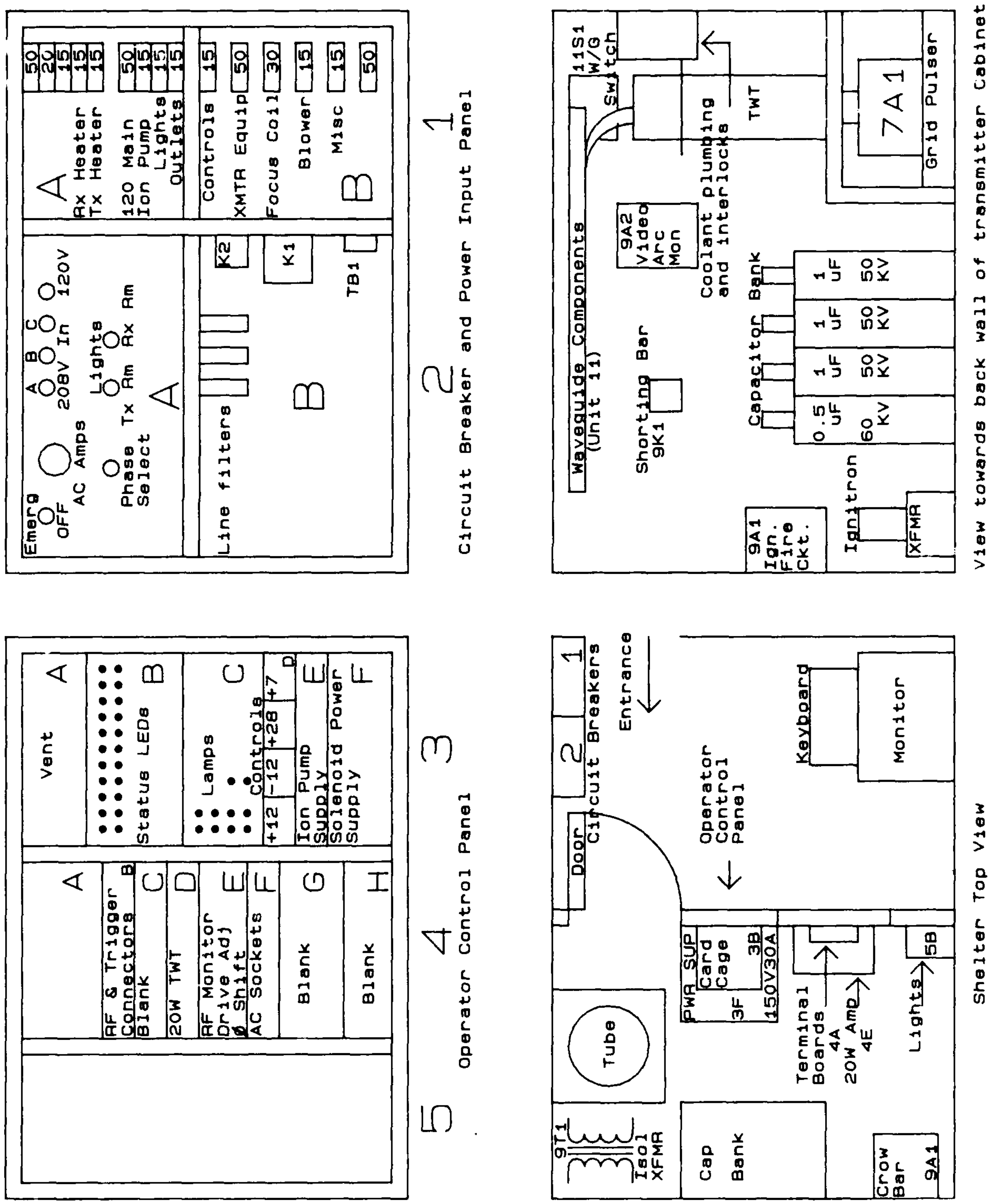


Fig. 2-1. Transmitter Layout and Unit Numbering

2. CONFIGURATION DESCRIPTION

To avoid confusion between the two transmitters yet allow components to be identified, a new numbering system was used to call out separate units in the new transmitter. The numbering system is as follows (refer to fig. 2-1):

Right hand wall of operator compartment:

Unit 1 - Power line input breaker panel
Unit 2 - Power relays, indicators, filters, and meters

Interior wall (both sides):

Unit 3 - Interlock logic, controls, power supplies
Unit 4 - Driver TWTA, video & RF connectors, terminal boards
Unit 5 - Transmitter compartment lights

Left wall of operator compartment:

Unit 6 - Input bulkhead connectors, video console

Right hand wall of transmitter compartment:

Unit 7 - Tube, grid pulser
Unit 8 - Flow interlocks

Back wall of transmitter compartment:

Unit 9 - Ignitron, Arc monitor, cap bank, drop bar

Left wall, transmitter compartment:

Unit 10 - Reserved for high voltage power supply

Ceiling:

Unit 11 - Waveguide

As shown in the layout, the unit number is followed by a letter indicating its position within the panel, if applicable. Then that is followed by an Assembly number (A-xxx), a terminal board number (TB-xxx), or component designation such as J for jack, K for relay or U for integrated circuit. Three-digit nomenclature found in this or other S-band documentation may refer to the other transmitter (e.g., 280A4A1), sometimes preceded by a WBA-, which was the original RCA designation.

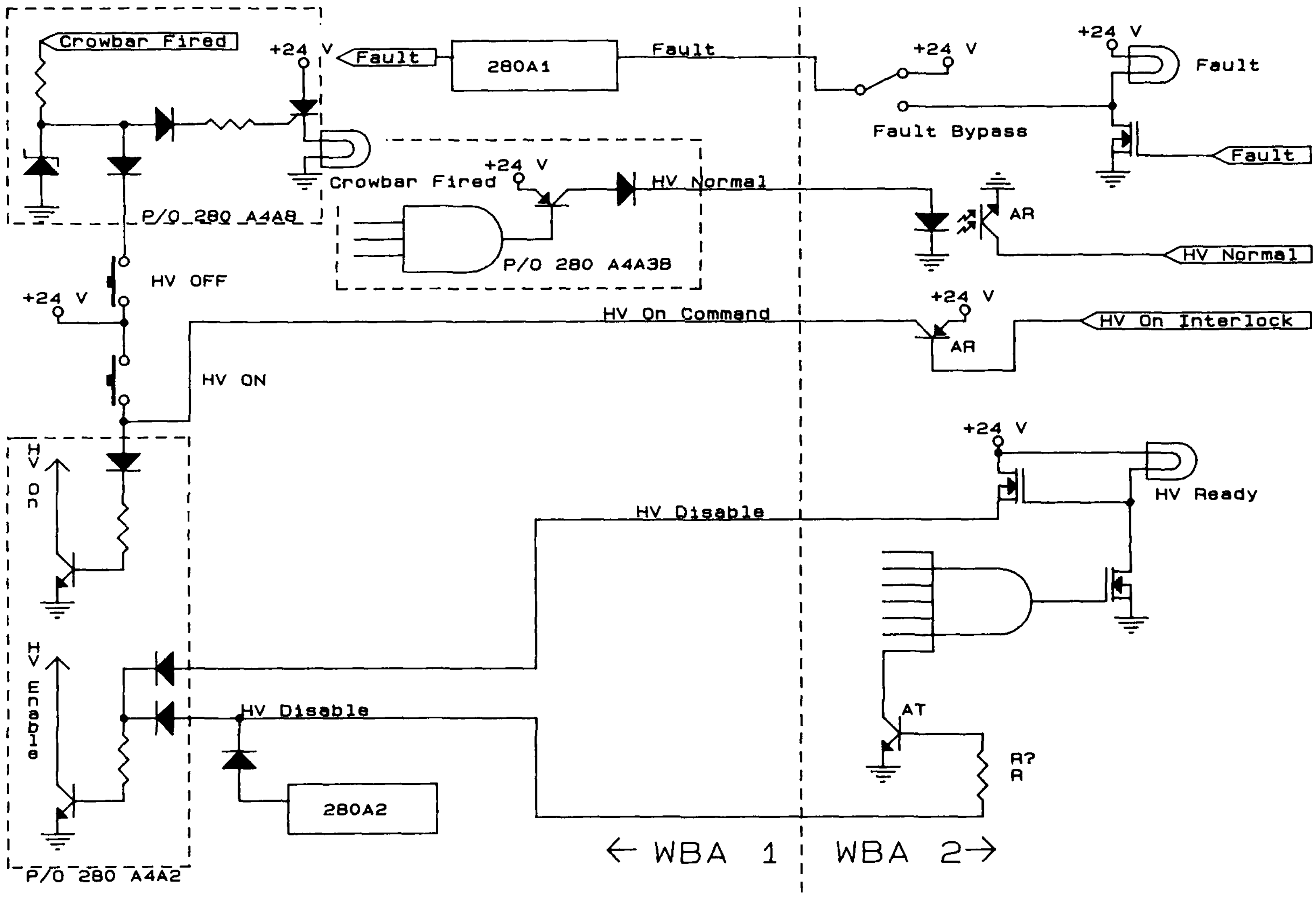


Fig. 3-1. Control Interface with WBA 1

3. TIE IN TO WBA 1

As mentioned in the introduction, WBA 2 was added to the existing transmitter power supply. Interlocks and controls had to be connected between the two to add the second tube capability. Since the components and design philosophies of the two differed, some accomodations had to be made.

WBA 2 uses TTL logic extensively, whereas WBA 1 uses discrete transistor logic at a 25 volt level which is similar to the relay logic of radar transmitters of 20+ years ago. In order to interconnect the two, discrete drivers were used with 25 volt power, and optoisolators to connect signals into the new transmitter logic.

Refer to fig. 3-1. WBA 2 has a drop bar which is normally closed, preventing high voltage operation. Thus the prime power must be on for normal operation. Control over WBA 1 is limited to turning the high voltage on and off manually and disabling high voltage in case of malfunction. The latter function is done by two paths; one is at the end of the high voltage interlock chain and inserts a 24 volt signal into the HV disable line of WBA 1 when all interlocks indicate high voltage turn on is acceptable (second from bottom interface line in fig. 3-1). The second path is through the fault detection chain, which normally sends 24 volts to 280A1 (top), an optoisolator previously used for waveguide pressure. When a fault is detected this goes to ground, interrupting high voltage. An electronic crowbar discharges the high voltage if a tube arc is detected (see chapter 9).

Another interface ANDs the HV disable signal from WBA 1 (bottom) into the HV ready line in WBA 2, allowing turn-on from either transmitter. When the HV is up to 40 KV, the HV Normal line is fed to WBA 2, where it is ANDed with other interlocks to form the Pulsing Enable signal.

The new transmitter was designed for maximum flexibility in recognition of the fact that it is a research vehicle and is apt to be reconfigured for various purposes. The transmitters can be separated electrically if, for instance, the tube in WBA 2 has a problem yet WBA 1 must be used. The power supply connections can be removed and the wires pulled back. Bypass switches are provided for the coolant flow and fault interlocks.

Fig. 4-1. Operator console

4. INTERLOCKS, CONTROLS, AND FAULT DETECTION

The control system of WBA 2 allows turn on and turn off procedures to be executed in an orderly fashion, protects the transmitter from damage, and allows a limited amount of operator intervention. Fig. 4-1 shows an operator at the video terminal which controls the operation of the Surveillance Lab through the HP-1000 computer and the Waveform Generator. The control panel is to the right of the operator. From this position, high voltage can be turned on or off, transmit triggers can be controlled (through software), and WBA 2 can be operated. For safety reasons, powering up WBA 1 requires the operator to be present in the other shelter.

Some of the protection circuitry needs to work faster than others to protect the tube from high voltage arc damage, and is implemented in the crowbar control subassembly (see 4.3 below).

4.1 INTERLOCK LOGIC

For many years transmitter interlocking was accomplished by relay logic. The obvious disadvantages to that approach are size, reliability, and speed. Modern low power Schottky (LS) digital logic is able to perform the same logic functions but has some disadvantages of its own. The speed which is an asset in most circumstances is a result of the high bandwidth of the transistors used, which have micron-sized features. The transient noise pickup and voltage overload capability of the inputs and outputs is lower than standard TTL logic, and much less than relay logic. When this type of logic is placed in the transmitter environment it is subjected to large amounts of EMI which are generated by the fast current risetimes of the tube. It is difficult to shield this noise at the source because high voltage needs a lot of air space for insulation; in this case, the 40 KV on the cathode of the tube requires 4 inches of air for effective corona suppression. Since the control circuits are small by comparison it is easier to shield them.

The interlocks are housed in a card cage designed for S-100 Bus usage which has been modified to add extra shielding that totally encases the circuitry (shown in fig. 4-2 with the rear shield removed). The card cage is mounted on an internal partition which forms a 19 inch rack. On the other side of the connector panel are the status LEDs shown in fig. 4-4.

Shielded cables are used to bring signals in without breaking the RF integrity of the box. Past experience has shown that the construction used would not be adequate at higher levels of RFI, but it was adequate for this job. A TEMPEST quality box would have been used if available.

After the card cage and mechanical layout was done, the

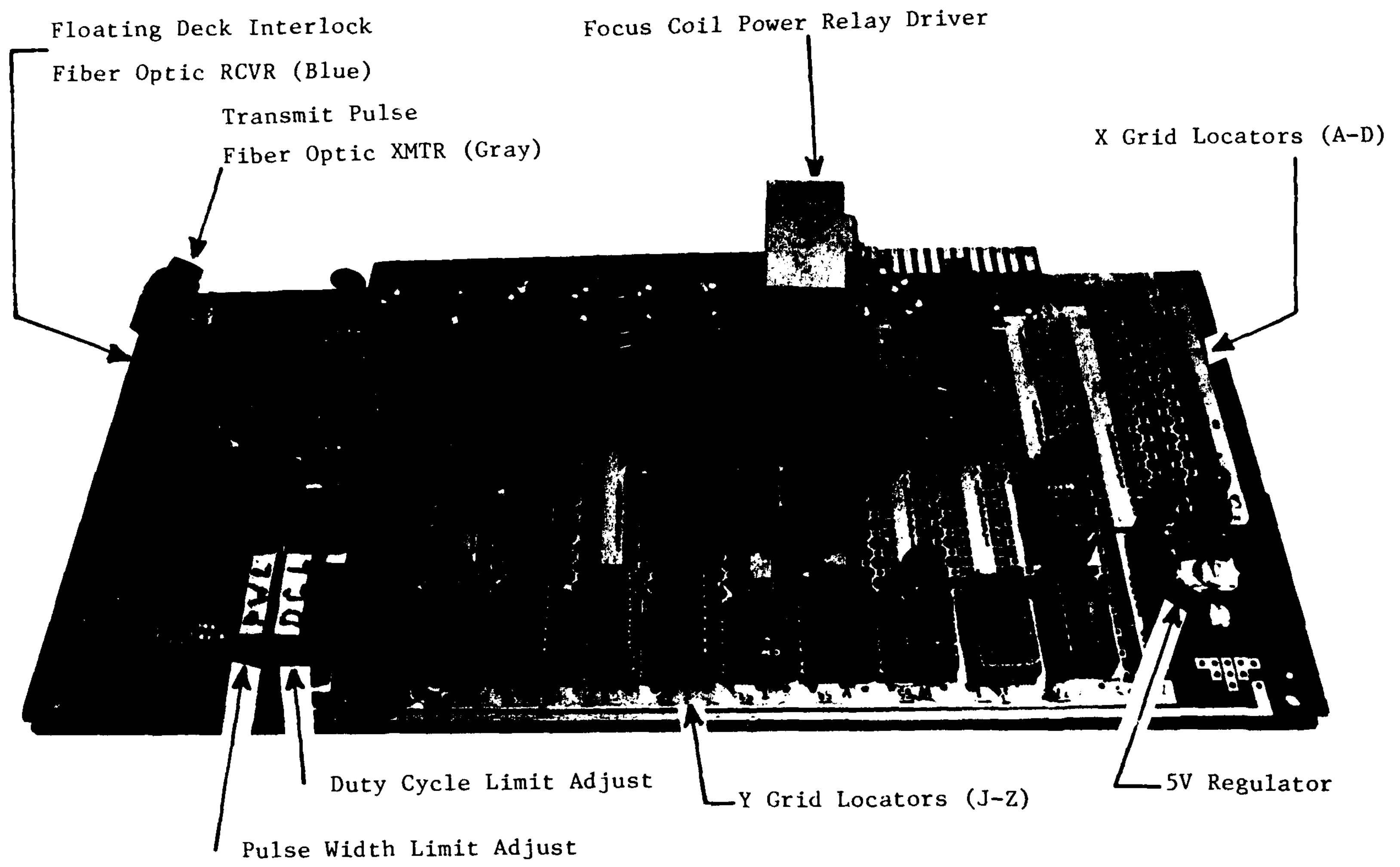


Fig. 4-3. Interlock Card

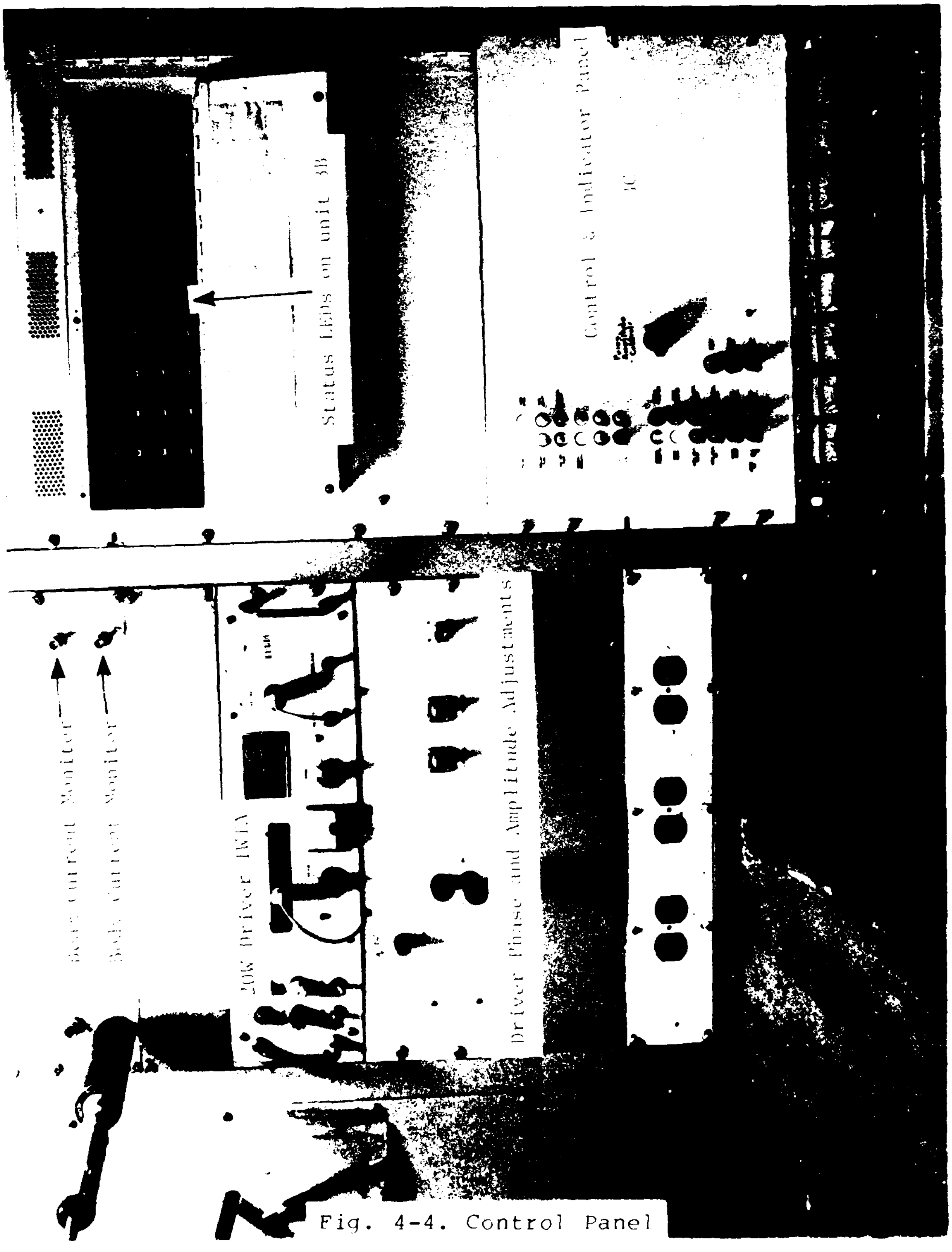


Fig. 4-4. Control Panel

circuits were designed and wirewrapped on a commercial S-100 board (fig. 4-3). Discrete circuitry is soldered onto header boards which plug into 16 pin IC sockets, thus facilitating repair. After all the circuitry was done, only half of one board was populated. This is a major reduction in size from a relay interlock chain or even the logic of WBA 1. The other slots in the cage are available for future use, such as control of a set of high voltage power supplies or interfacing with the HP 1000 computer which controls the waveform generator in the lab.

Fault and monitoring status LEDs are mounted behind a drop down panel, shown in fig. 4-4. The only lights on the front panel normally visible to the operator are system status and fault summary lights on unit 3C. This arrangement allows a large number of status points to be monitored when necessary without confusing the operator with a large number of blinking front panel lights, most meaningless.

Operator inputs are momentary mechanical contact pushbuttons on the front panel, in a layout which mimics WBA 1 to reduce operator obfuscation. This type of switch works very well with relays but with LSTTL logic, there may not be enough switching current to keep the contacts clean. Also, the contacts bounce and send multiple signals into the logic, thus precluding direct operation of a toggle latch (it could toggle hundreds of times, coming to rest at a random state). WBA 2 uses RS flip flops and RC decoupling at each switch to reduce switch bounce problems. In retrospect, these should have been integrated into the interlock logic shielding to reduce EMI and electronically debounced.

4.2 INTERLOCK OPERATION

Fig. 4-5 introduces the schematics. Since many of the components are of one value to reduce spare parts requirements, these are identified in the chart and pinouts of several devices are also shown.

Fig. 4-6 is a block diagram which shows how the different operating states of the transmitter are controlled. These states are the prime power, high voltage, and pulsing and are shown across the middle of the diagram.

The prime power interlock (fig. 4-7) has no inputs except the on/off pushbuttons and a time delay which holds power off for 50 ms after application of control power to eliminate false latching by the other circuitry. It operates the heat exchanger, the floating deck, and other prime power.

The floating deck interlock shown in fig. 4-8 is a light pipe signal sent from a summary fault indicator in the grid pulser and received in the light pipe receiver on the left side of the board in fig. 4-3. It is fail-safe in operation; if the

Notes to Schematics

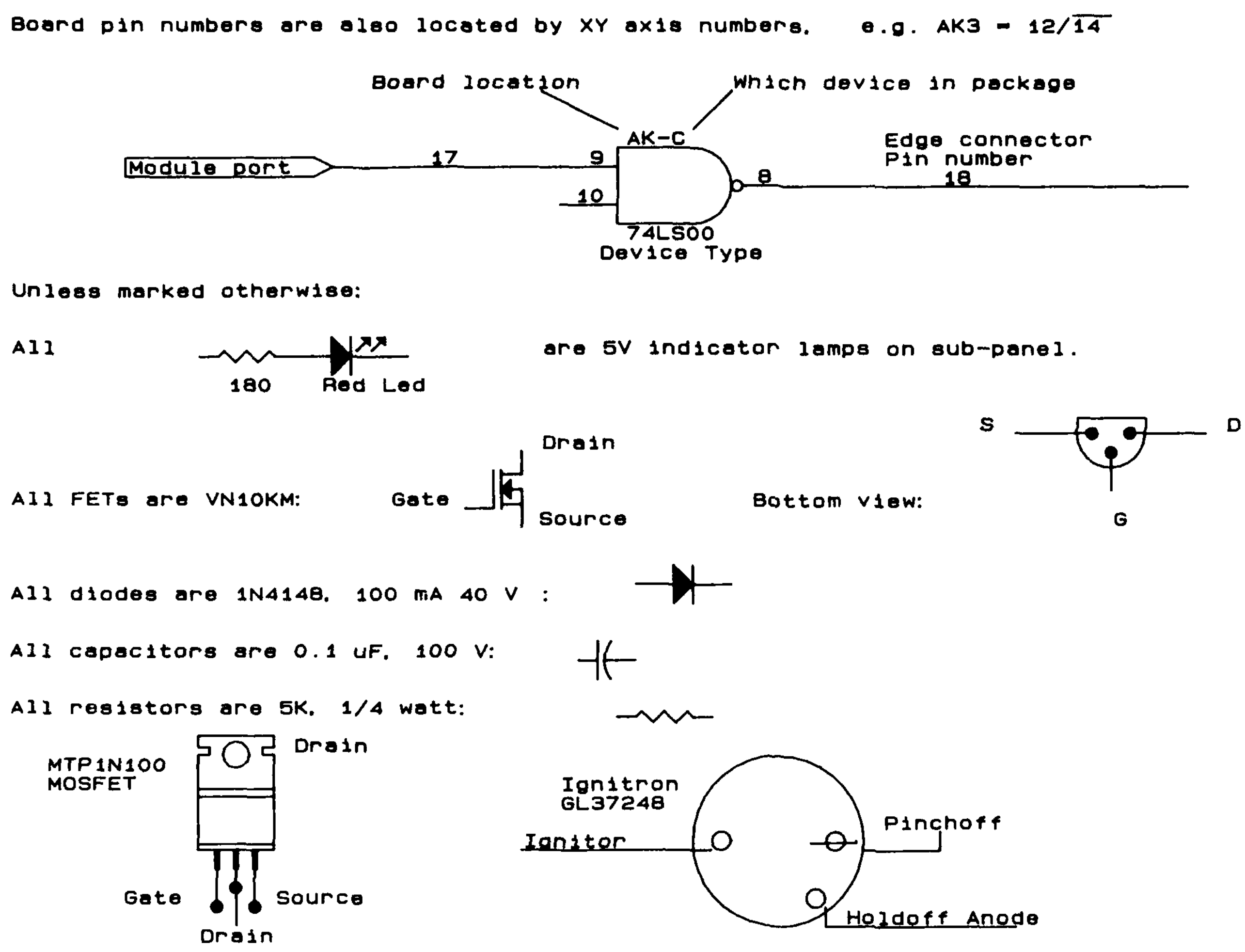


Fig. 4-5. Notes to Schematics

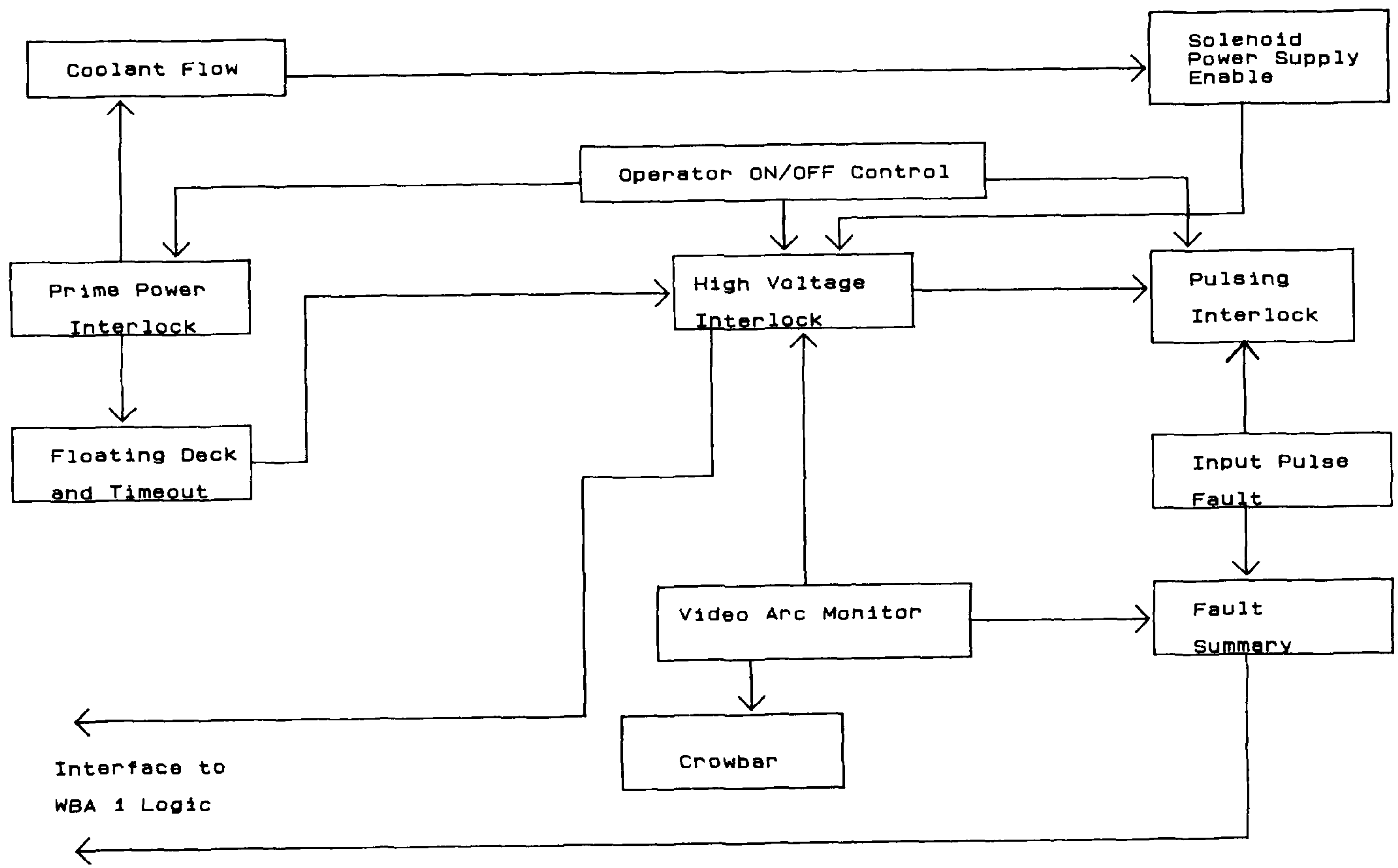


Fig. 4-6. Interlock Block Diagram

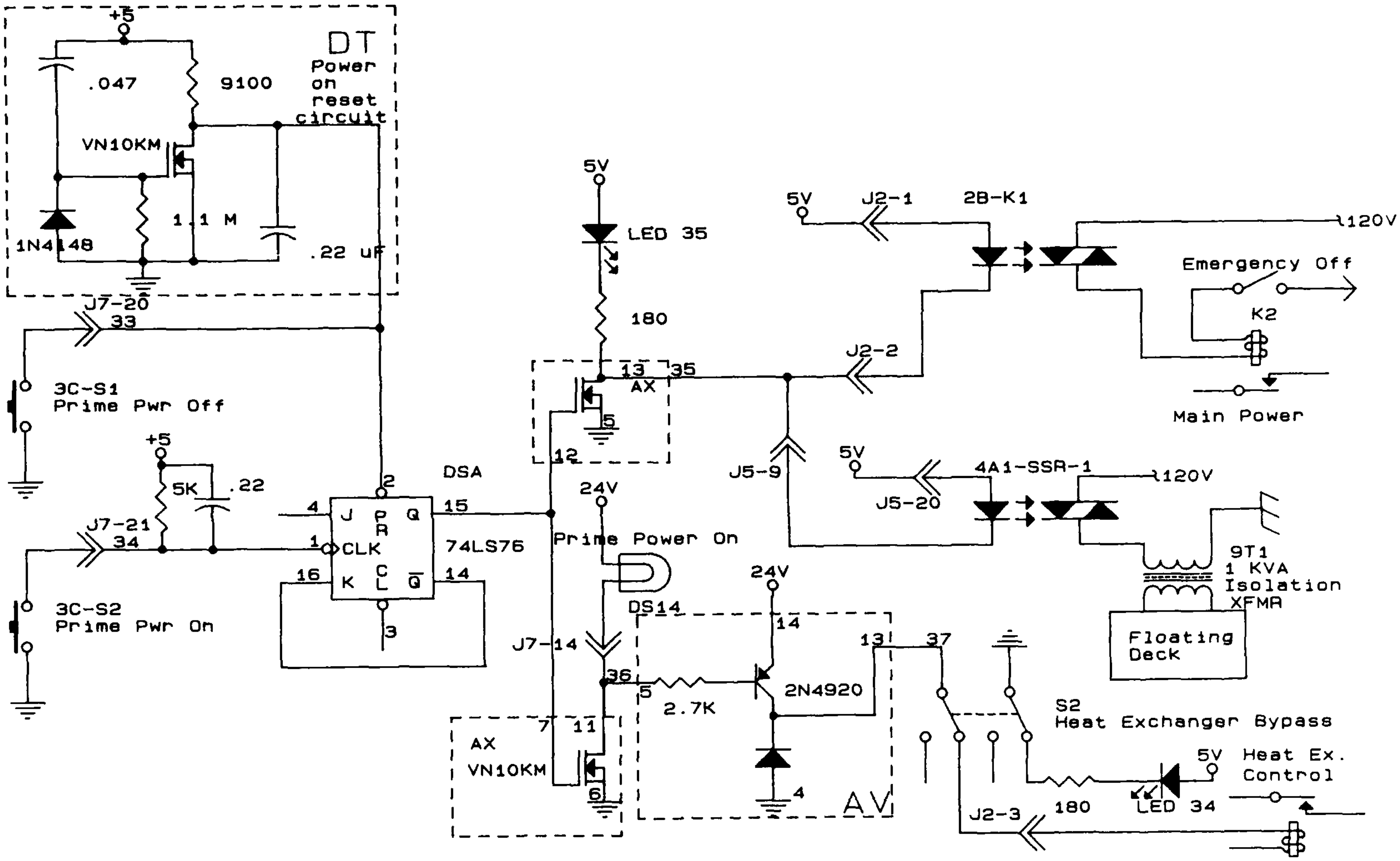


Fig. 4-7. Prime Power Interlock

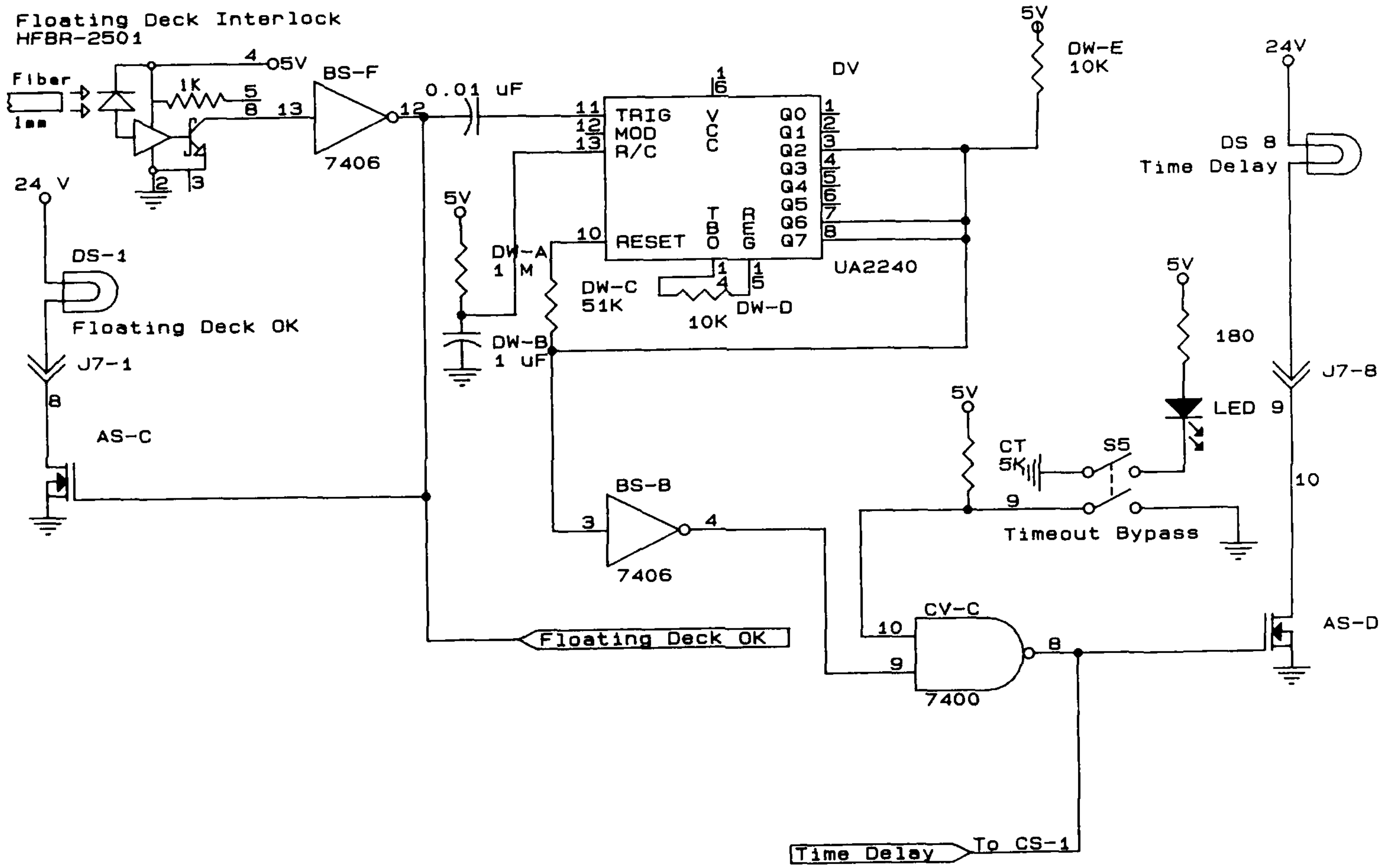


Fig. 4-8. Floating Deck Interlock

light is cut off, pulsing action immediately ceases and the high voltage is disabled. Thus the tube can conduct, if the pulser hangs up, only as long as the capacitor bank allows. After the tube warms up, the floating deck sends this fiber optic signal to the 5 minute timer shown in fig. 4-8. The 2240 consists of a 555-like timer followed by 8 stages of counters, so it divides the RC determined timer period by up to 256. Any time the floating deck interlock is interrupted, the high voltage is disabled through this chain.

When the heat exchanger builds up enough flow, the coolant interlock (fig. 4-9) turns on a small relay in the focus coil power supply (FCPS). The FCPS prime power is controlled by the prime power interlock, but the small relay (3PK1) controls the regulated output voltage. When the coolant flow is satisfactory, it commands the output voltage to go from a few volts to 150, where it goes into current regulation mode. If coolant flow is lost, the output voltage will revert to near zero so that the focus coil is protected against burnout (it takes 3500 watts to operate it). The focus coil current is detected by a reed relay rewound with 6 turns of the power supply output current wire. The reed contacts are fed to the high voltage interlock (fig. 4-10).

The high voltage interlock ANDs together a number of signals such as the drop bar microswitch, door switch, and HV ready line from WBA 1. If these are all high (and stay high) the HV ON button will toggle the latch, sending a +24 V signal to the power supply in WBA 1 to turn it on.

When the voltage divider in WBA 1 senses the proper operating voltage (-41 KV), it sends a HV Normal signal to the pulsing interlock, fig. 4-11. It is ANDed with the waveguide arc detector, coolant flow and others to enable the pulsing interlock latch, DP-B. When latched on by the Pulsing On pushbutton, it allows the input pulse trigger from J9 to be sent to the floating deck via a fiber optic cable.

The input pulse duty cycle/pulse width fault circuit (fig. 4-12) is an analog circuit which roughly detects whether the input trigger pulse from the Surveillance Lab is within limits specified for the tube. The circuits are basically similar but have different time constants; the duty cycle sensor works over a longer period, in the millisecond range. The incoming pulse is fed to 2 RC networks. If it is longer than 300 usec, it brings the gate of the Pulse Width limit FET up to the threshold voltage, turning it on and latching the PW fault latch. If the duty cycle is greater than 6%, the Duty limit FET is turned on. This circuit provides an additional safeguard to the tube and power supply, rather than relying on software and AC circuit breakers.

4.2.1 INTERLOCK INPUTS

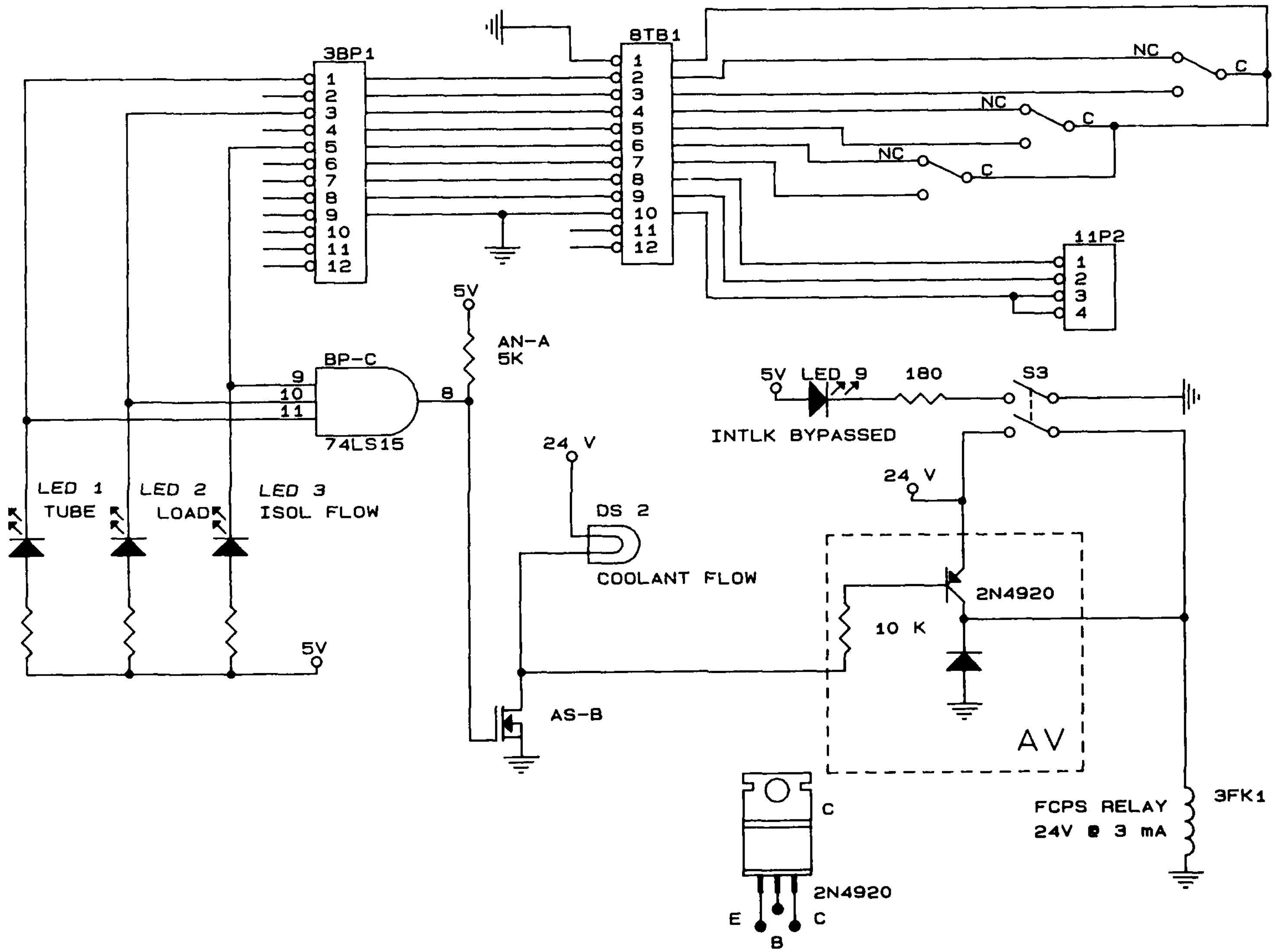


Fig. 4-9. Coolant Flow Interlock

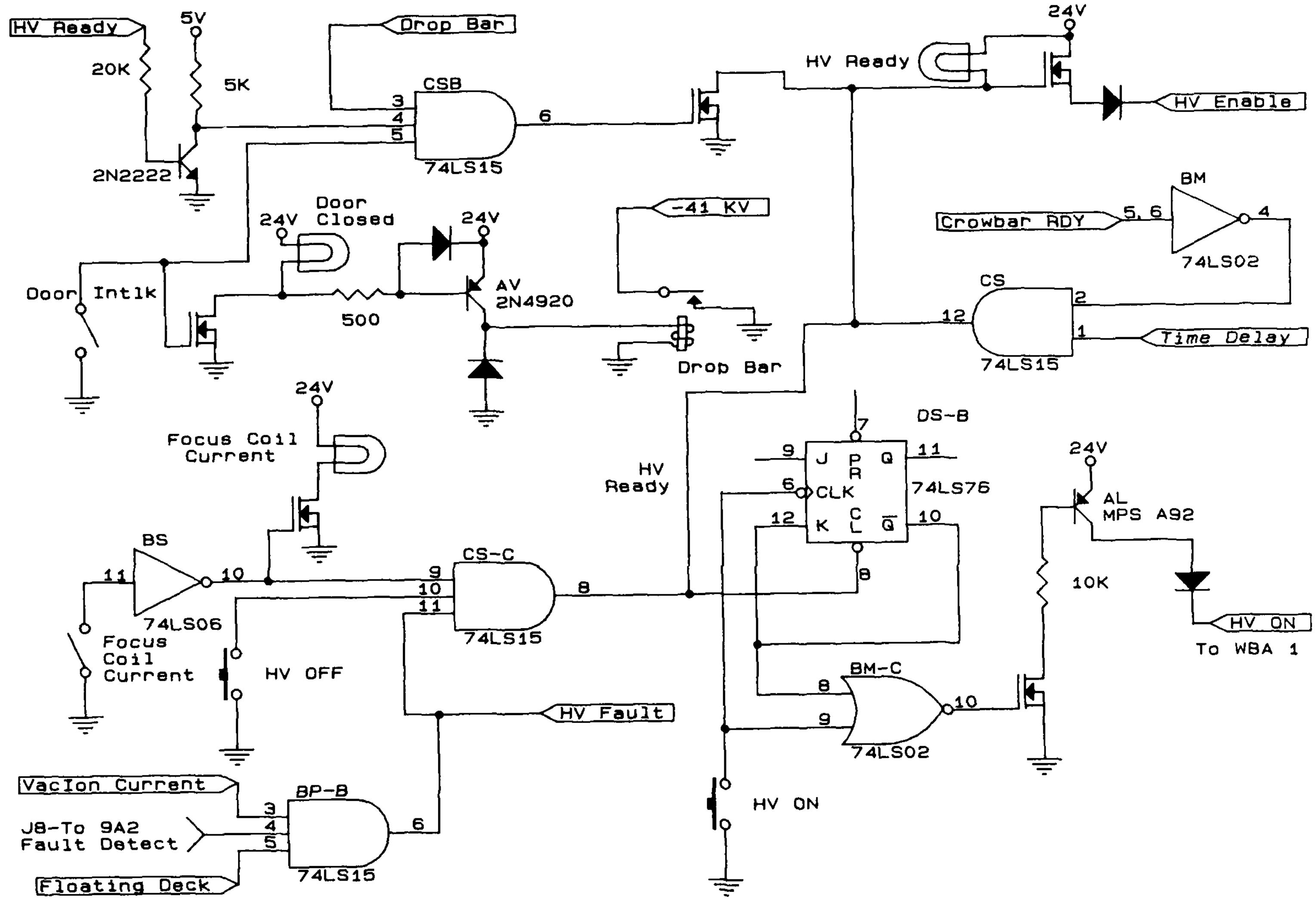


Fig. 4-10. High Voltage Interlock

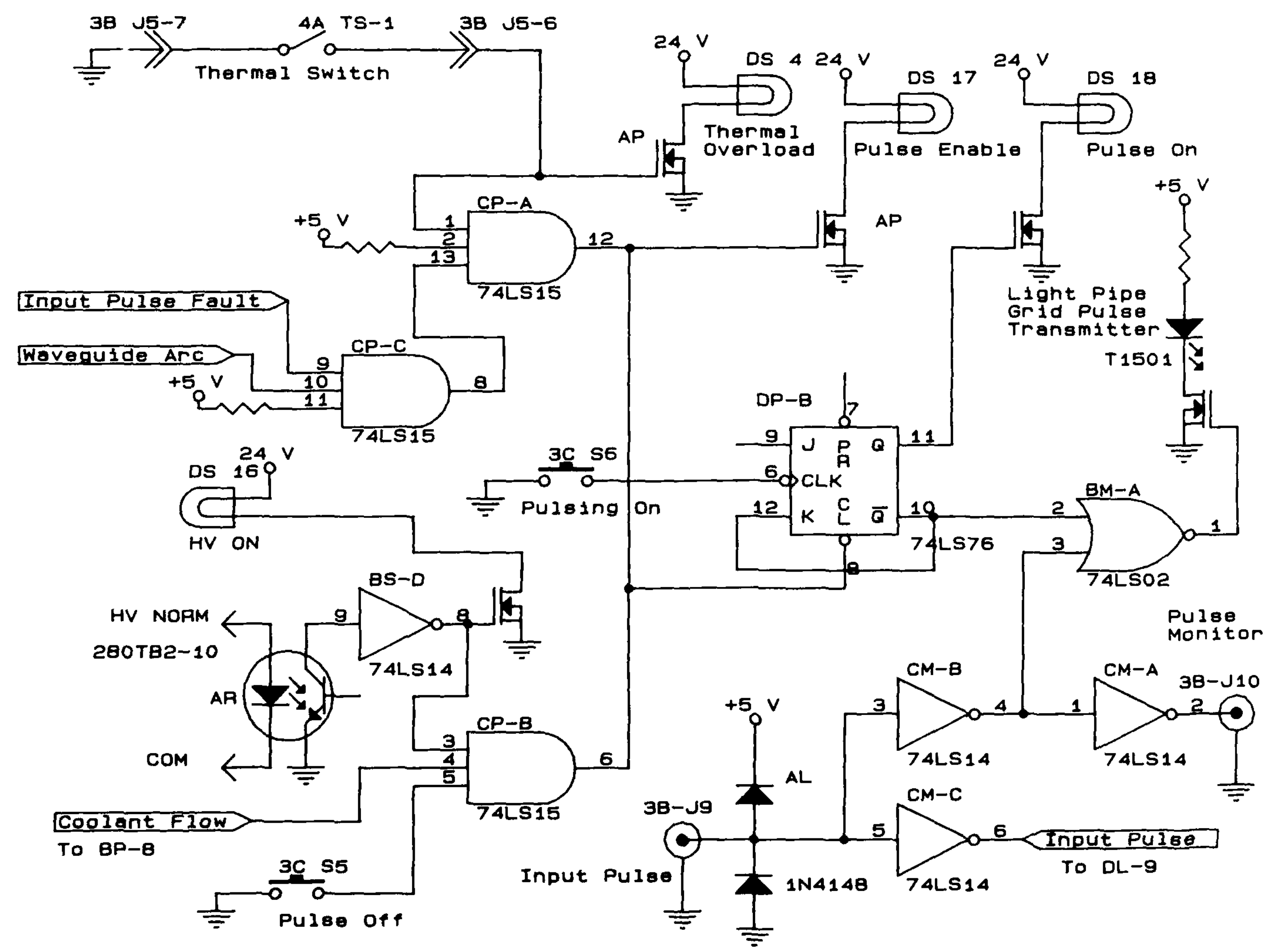


Fig. 4-11. Pulsing Interlock

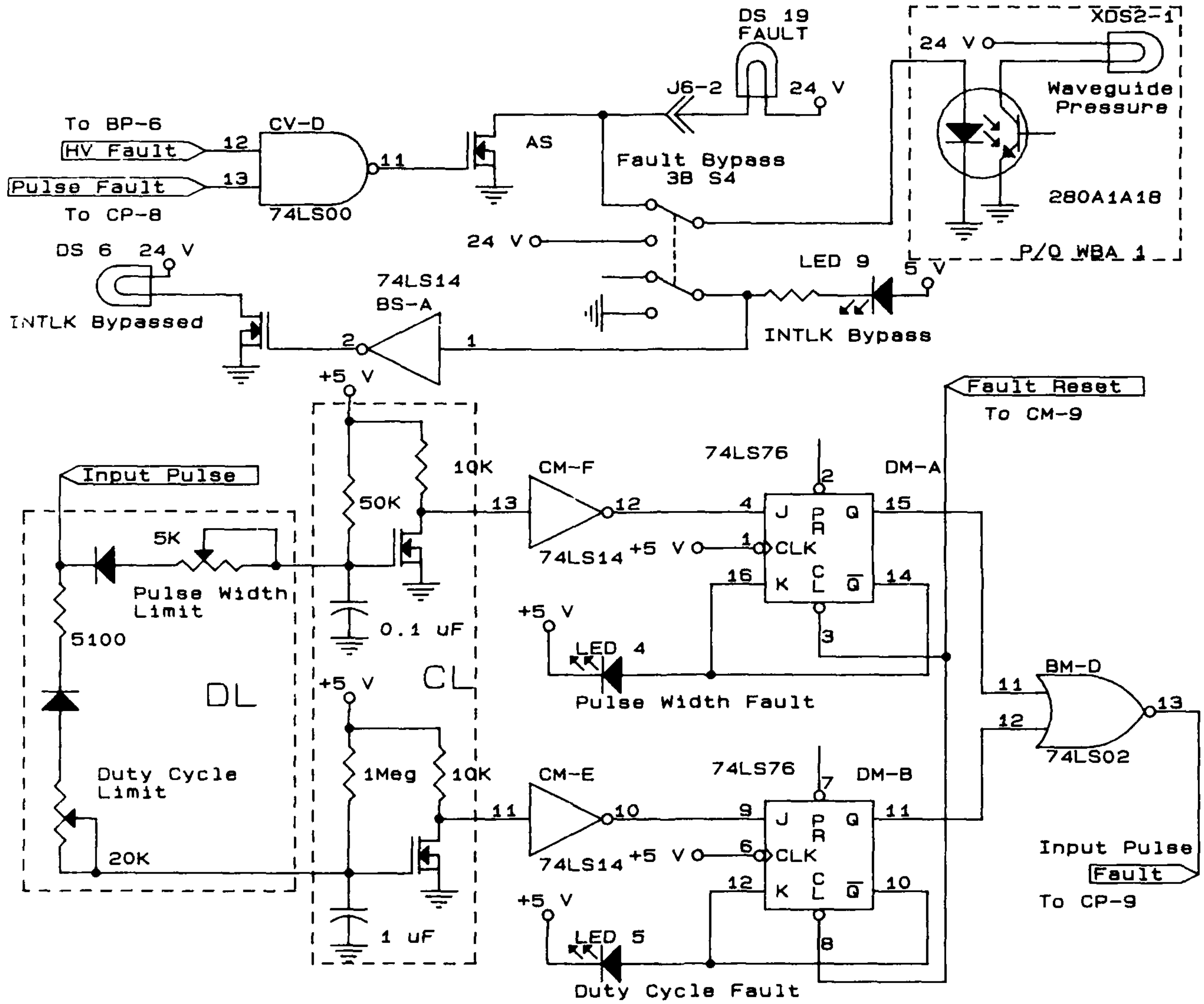


Fig. 4-12. Pulse Fault Detector and Fault Summary

Floating Deck (Grid Pulser) OK - Light pipe
Transmitter HV compartment Door closed
Coolant Flow - Tube, load, and Isolator
Thermal Overload
Drop Bar Down
Waveguide Arc
Input pulse duty cycle/width fault
Crowbar ready
Ion pump current

4.2.2 CONTROL INPUTS

Prime power on/off
Emergency Power off
High Voltage Ready (Automatic from WBA 1)
Pulsing On/Off
High Voltage On/Off
Timeout Bypass
Coolant Flow Intlk Bypass
Grid Drive Voltage
Waveguide Arc Sensor Test
Fault Reset
Heat exchanger Off

4.2.3 CONTROL OUTPUTS

Focus Coil Power Supply Enable
High Voltage Power Supply Enable (to WBA 1)
Mechanical Crowbar Coil
Grid Pulse (Light Pipe)
Grid driver Voltage (light pipe)
HV ready (to WBA 1)
Crowbar fire

4.3 CROWBAR CONTROL

In designing a transmitter, increasing the size of the high voltage capacitor bank reduces the amount of ripple which the regulator must deal with, and reduces the amount of voltage droop which produces phase and amplitude abberations. The larger the capacitor, however, the more energy which may be dumped into a tube during an arc inside the tube. The WBA deals with this problem in two ways. First, the size of the capacitor bank is smaller than a 60 Hz main power supply would require, because it operates at a higher switching freqency and needs to store energy for a shorter period before it is refilled by current pulses from the supply. Secondly, the currents are monitored to detect irregularities and an electronic crowbar is connected across the capacitor bank to dump the energy quickly if an arc is detected.

4.3.1 CURRENT MONITORING

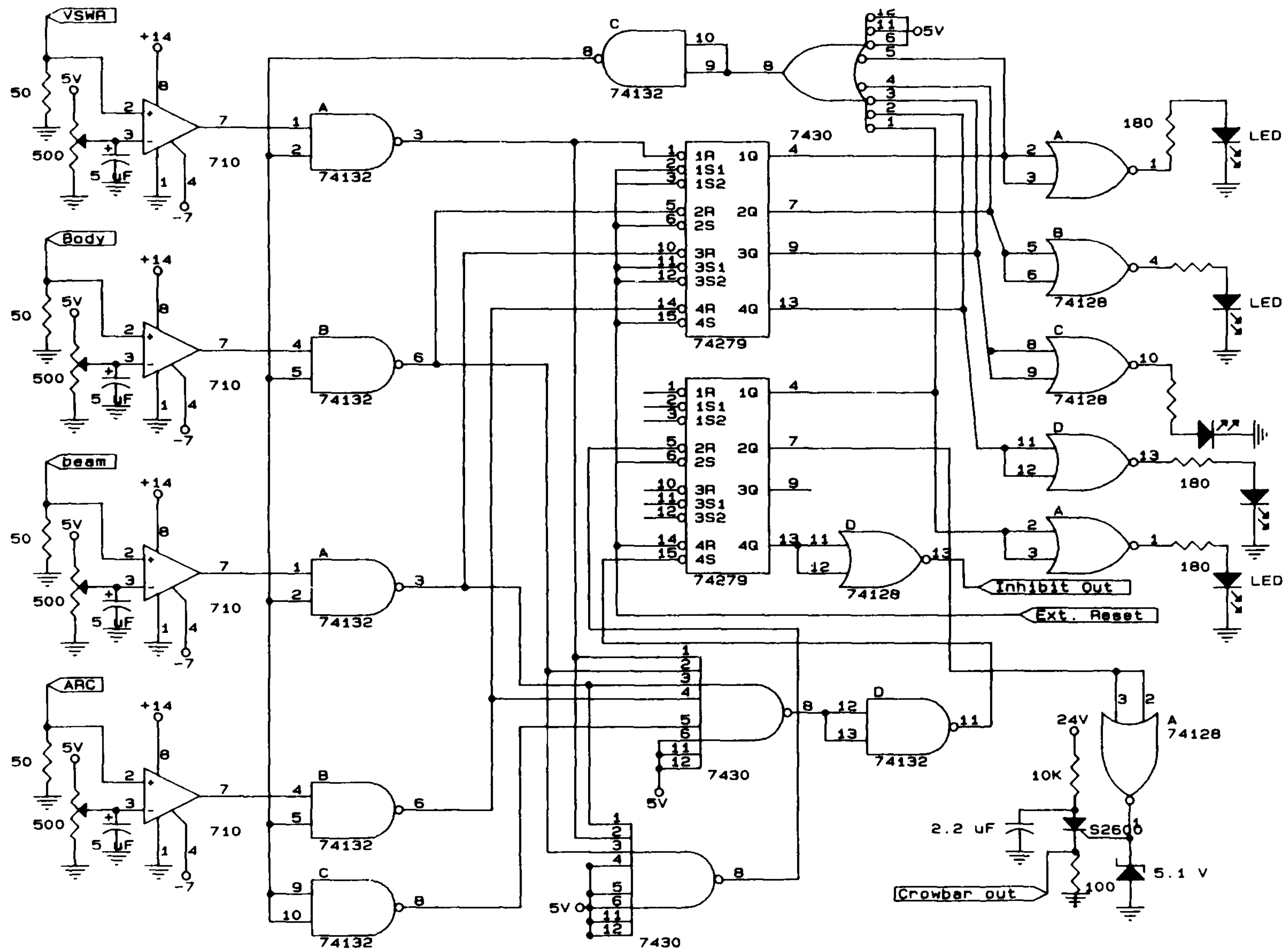


Fig. 4-13. Video Arc Monitor (9A2)

Currents flowing into the tube are sensed by current transformers, shown in fig. 1-3 above the video arc monitor. These devices consist of a toroid of magnetic material with a single coil wound on it. The primary of the transformer is formed by a wire which the user passes through a 2 inch hole in the center of the toroid. This wire is insulated since the cathode is at -41 KV and the transformer is grounded. The output of the transformer is calibrated and matched so that it gives a specified volts per amp (transresistance) ratio into a specified load. The Pearson transformers used are specified into a high impedance load such as an oscilloscope; since 50 Ohm cable was used, with a 50 Ohm matching resistor inside the crowbar controller, the transformers were recalibrated. The voltage output is divided by half, as expected by an analysis of the circuit.

The physical location of the current transformers is shown in fig. 6-1. The collector current transformer is simply slipped around the collector lead. The body current sensing is more difficult, since the tube body is grounded. In most transmitters, this situation is neatly sidestepped by running both the collector and cathode leads through the body current transformer. This subtracts them and the net result is the current that goes elsewhere, i.e., the body. In any circuit, however, there are stray fields and capacitances which do not perfectly add, thus putting submicrosecond "ears" on the pulse which could be above trip levels of the protection circuitry. There is actually some body current "ears" on the pulse due to defocusing of the beam during rise and fall time of the pulse. It can be very difficult to get these currents to subtract perfectly. In the end they can be swamped out with a capacitor of as small a value as possible. This, of course, slows down the response.

4.3.2 VIDEO ARC MONITOR

The high speed capability of the crowbar demands an equally speedy controller. The controller built for WBA 2, shown in fig. 4-13, is adapted from a design built for a short pulse magnetron transmitter, which had much higher EMI and greater speed requirements. The time elapsed from trigger input to fault trigger output is less than 100 microseconds.

The controller has the capability of sensing several different inputs, and latch and lockout circuitry to allow only the first fault that occurs to indicate on the LED displays. This was done because one overcurrent could result in another overcurrent when the crowbar is fired, and the currents generated by the crowbar itself generates enough EMI to trip the sensitive crowbar circuits. With the latch and lockout circuit, the first fault indication is held until the operator resets it.

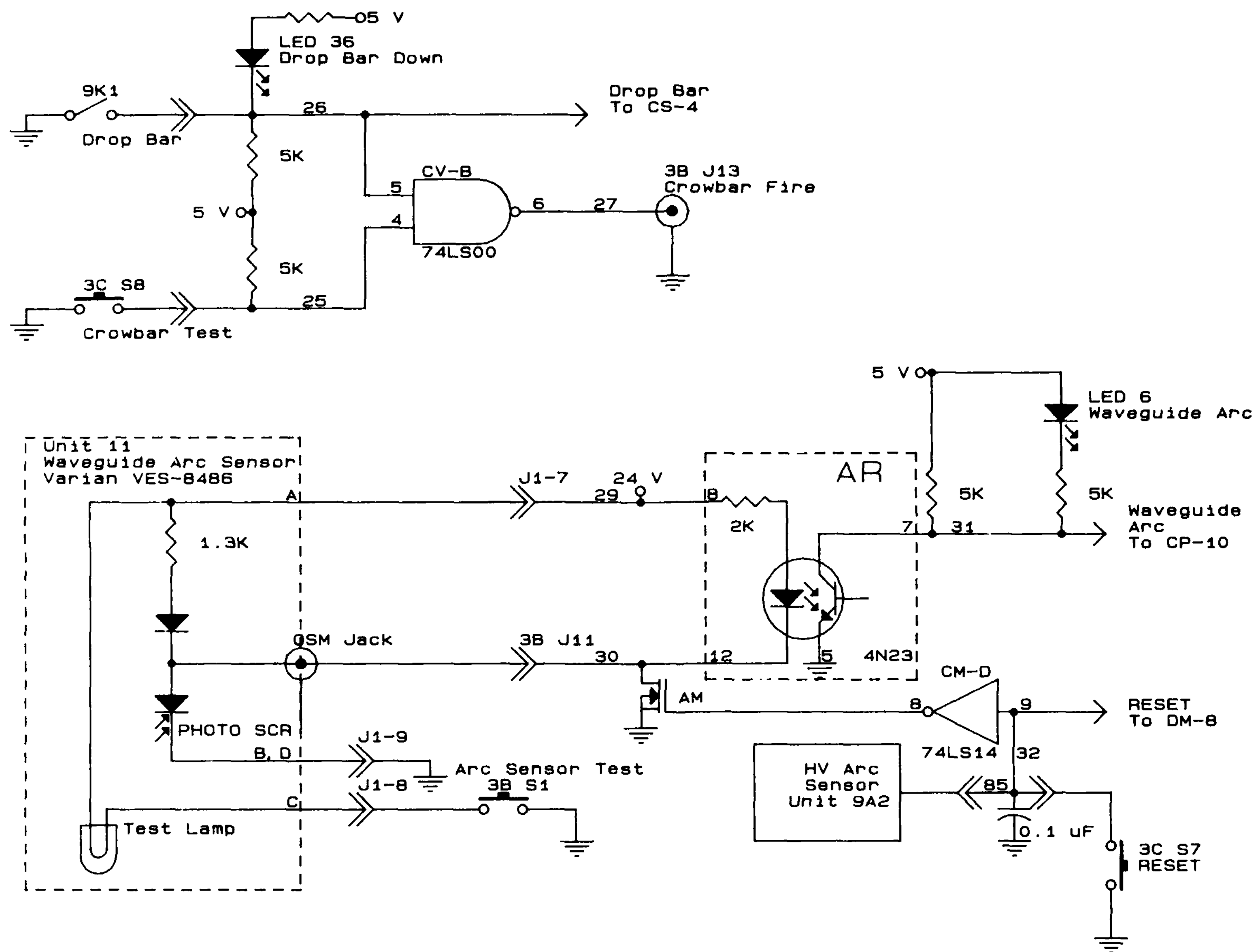


Fig. 4-14. Waveguide Arc Sensor and Crowbar Test

Each input signal is fed into the input of a 710 comparator and compared to an internal reference voltage set by a pot. The output of each comparator goes into a 2 input NAND gate. The other gate input supplies the lockout signal. The outputs of each gate are latched in flip flops, and then ANDed together to generate the lockout signal. The first comparator to fire therefore locks out each succeeding comparator fault signal, thereby identifying the fault which knocks the transmitter off the air. Signals from the AND gates are selectively combined into one of two AND gates; one merely inhibits pulsing, the other fires the crowbar in addition. The arc sensor and VSWR signals need not fire the crowbar since shutting off the RF removes the damage potential, whereas the high voltage must be discharged to clear a tube arc. The operator clears the fault logic by resetting the flip flops through a RESET line from the logic which is controlled by a front panel pushbutton.

The controller is mounted physically close to the tube to minimize the cable runs (upper left in fig. 6-1). Solid 50 Ohm coax and a cast zinc box were used to eliminate noise pickup. A much more exhaustive description of the crowbar trigger, with photographs and wiring layout, along with theoretical derivations and experimental evaluations of impulse noise pickup in shielded enclosures, are found in RADC TR-84-77, "Impulse Beam Controller and Crowbar Trigger for High Power Microwave Tubes".

4.5 WAVEGUIDE ARC SENSOR

A commercial waveguide arc sensor, fig. 4-14, is installed on the output of the tube to shut off RF in case of a waveguide arc. The heart of the sensor is a photo SCR which is focused on the window of the tube. A waveguide arc would either start at or propagate to the window of the tube, possibly damaging or breaking it. The photo SCR detects the light generated by the arc and latches on, turning on the 4N23 and sends a signal to the video arc control which turns the pulsing off.

Fig. 5-1. Grid Pulser

5. GRID PULSER

This section documents the grid pulser which modulates the TWT. Despite its small size, it represents a disproportionate amount of the effort expended on the WBA 2 project. Because of the limitations of conventional pulsers, a completely new design was done using recently available technology. This resulted in a unit which was smaller, more efficient, more maintainable, more flexible, and provided superior performance. The original pulser was a breadboard version using available components, and was modified extensively until good performance was achieved. It was replaced by an updated, cleaned up version using better components and construction techniques (fig. 5-1).

5.1 GRID MODULATOR PROBLEM

Grid modulators or pulsers have been a vexing problem since high power microwave tubes have been used. The typical TWT has a high transconductance shadow grid which lies near the cathode surface. The proximity to the cathode reduces the voltage wing required for modulation, but it contributes to capacitance which the grid pulser must charge and discharge. This capacitance, the rise time requirements on the pulse, the grid current, and the voltage swing are entered into the circuit design. From this the designer must ascertain the peak currents required, along with other requirements such as pulse top ripple, physical size, etc., then set to work designing the switching circuit. Sometimes the requirements must be scaled down due to impracticality of reaching the objectives.

5.2 WEIGHT REDUCTION AND EFFICIENCY

Most grid modulators are large, heavy, and power hungry. A suitable commercial unit, which was used on the Surveillance Lab L band transmitter built in 1978, weighs 80 pounds without the heater supply and consumes a kilowatt of prime power. The use of tubes for switching, 60 Hz transformers, linear regulators, and elaborate pulse shaping circuitry contributes to this problem. The WBA 2 pulser is different in many ways.

The design first started with the equivalent circuit of a traveling wave tube grid. The amount of actual grid current drawn is small (approximately 50 ma). The amount of bias current drawn is negligible. The greatest power drain is the charge stored in the capacitance of the grid, which is lost when the grid is switched. This must be calculated at the highest PRF. Ideally, the amount of power required was only a few watts. Unavoidable circuit losses added about 10 watts. The 150 watt heater supply consumed most of the power in the floating deck.

The pulser design proceeded from the premise of using the minimum amount of power required. This produced a design which

ran cooler, consumed 200 watts including heater, and weighed about 10 pounds mainly due to the elimination of 60 Hz transformers. It is provided with a handle for single handed carrying. For maintenance, it can be removed and plugged into 120 VAC power and operated on the bench. The WBA 1 pulser must be serviced in place, which is difficult owing to its location underneath the tube stand.

5.3 ACTIVE SWITCHING DEVICES

Due to the high voltage requirements of most high power tube grids, a tube circuit has usually been used in the past to effect the pulse switching. These tubes can have stringent requirements and sometimes have to be custom developed, such as in the E3-A radar. They tend to develop reliability problems, also. Tubes need a heater supply, a screen supply, and a grid pulser of their own, all floating. Thus the tube grid modulator tends to be a bulky, heavy affair full of custom magnetics.

The VTS5753 TWT used in WBA 1 and 2 requires up to 500 volts of positive grid drive and -600 volts bias. When WBA 1 was designed this level could be reached by stacking bipolar transistors in series to hold off the voltage. Suitable transistors were made by Delco Electronics and were intended for television receiver flyback applications. They performed suitably in the Digitally Coded Radar application because the pulse width was fixed at 300 microseconds. The big problem with bipolar transistors is storage time of the junction; they require about 7 microseconds to turn off. Also, the Delco line was discontinued and high voltage bipolar power transistors remain an elusive procurement problem.

The power FET has a higher saturation resistance than an equal area bipolar which limits its use in high current applications. The FETs used in the grid pulser are rated at 2 ohms. This is of little consequence in a high voltage circuit, however, and can be beneficial in that it limits fault (short circuit) currents. These occur on pulse circuits where there are both pulldown and pullup circuits which could crossconduct. In this case, the crossconduction is of very short duration but causes instantaneous currents well above the rated DC levels of the device.

Crossconduction was eliminated on WBA 1 by the use of only pullup stages working against a resistor connected to the bias supply. The disadvantages of this technique are slower speed due to the RC time constant formed by the resistor and the capacitance of the tube grid, and the power wasted by the resistor when the grid is on. In the case of WBA 2, the desire to shorten the minimum pulse width for high resolution applications dictated the use of a pulldown switch.

5.4 FET APPLICATION

The modern power FET has now been adopted by most designers of high voltage pulse generators as the replacement for medium power tubes. High power applications will, for some time to come, use thyratrons, thyristors, large hard tubes, and cross field switches because of the difficulty of paralleling enough FETs to achieve the power handling capability. The prospects of SITs (static induction transistors) are good, but the technology is still emerging.

5.5 HIGH VOLTAGE FET OPERATION

Series operation of FETs is possible with careful balancing of the voltage across each device. Avalanche breakdown protects each device if the voltage rating is exceeded, which protects the device from destruction. This, however, results in a sudden conduction through it, which puts that much more voltage stress on the rest of the series chain. A ripple effect could result in pulses being erratically generated. Thus balancing in the steady state is crucial to proper operation.

Transient overvoltage conditions during turn on, where one slower transistor has more than its share of voltage suddenly applied across it, tend to accelerate switching. Turn off is another matter; avalanche of any transistor could precipitate breakdown of the whole chain when it is supposed to be off, and the opposite polarity chain is pulling the opposite way. Obviously, this is to be avoided; one way is to slow down the circuit so the voltage comes up on all the stages slowly and none receives an extra "spike". Another method is triggering stacked stages from each other, through a variety of circuits, so that they automatically switch together. This type of circuit usually results in lower speeds than if the FETs are triggered in parallel.

5.6 SPEED AND PACKAGING

At this time, the limiting factor of the speed of a circuit using a commercially available FET is the package of the FET. Power bipolar packages such as the TO-220 plastic and TO-3 diamond shape are used. These packages have high parasitic inductance and capacitance and large discontinuities which cause mismatches at high frequencies. RF transistor packages have been used but they are expensive. An inexpensive, low parasitic package remains an elusive goal.

In the grid pulser built for WBA 2, TO-220 transistors delivered a rise and fall time of about 50 nanoseconds. Since this was satisfactory for the radar, the rest of the circuit was designed to this.

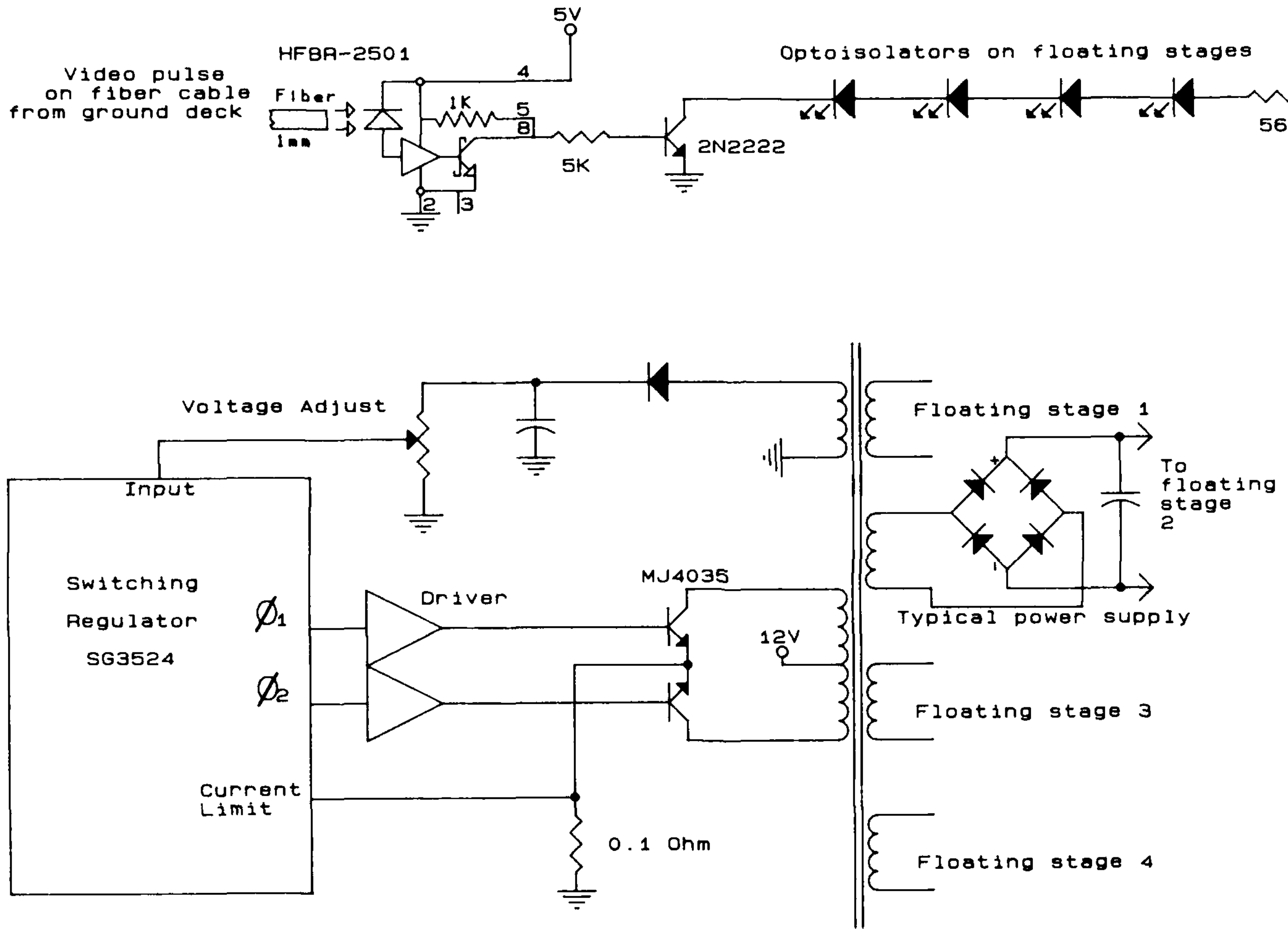


Fig. 5-2. Pulser Floating Power Supply

5.7 INTERSTAGE COUPLING

Coupling to driver circuitry tends to be of two types: magnetic and optoelectronic. Of the two, optoelectronic is the better behaved because the light signal is either on or off. Thus it is like direct coupling because it can remain on indefinitely; there is no restriction on pulse length or spacing. Speed of the optocoupler is then the limiting factor.

The pulse drive circuit used in the grid pulser is shown at the top of fig. 5-1. The transmitter gate pulse is coupled from the logic circuitry into the high voltage isolated grid pulser assembly via a fiber optic cable (top right in fig. 4-11). The receiver in the floating deck drives a chain of LEDs in optoisolators which couple the signal into the 4 stages of the grid pulser switch circuitry. The optoisolators used are rated at 10 MHz in data applications. This may seem slow, but the pulse is sharpened in the following circuitry. The limitation of the amount of sharpening allowable is the time jitter which results. This must be matched stage to stage to balance voltage transients.

Magnetic (transformer) coupling is an art in itself. A single transformer could couple the pulse, but this usually restricts both the minimum and the maximum pulse widths due to bandwidth limitations of the transformer. The usual approach is the generation of start and stop pulses, which are applied to individual transformers or one transformer combined with steering logic. However, the design must ensure that a short pulse does not trigger the pulser on without shutting it off.

5.8 DRIVING FETS

The original pulser used LM318 high speed op amps for the FET drivers which had to be boosted by a two transistor complementary symmetry output amplifier. The jitter and overlap of the various stages due to variations in the LM318s had to be carefully tuned out, and separate power voltages had to be supplied to each amp. At the time, the LM318 was the only way to achieve the speed required. However, power FET driver ICs have been recently developed which adequately drive FETS. They are adaptations of computer clock driver circuits which have high current outputs, ideal for driving the high input capacitances of the FETs. They also can be powered off the same voltages used to bias the FETs. The only problems encountered with them are in the case of the CMOS versions. If the outputs are allowed to swing outside the power rails, latchup can occur, destroying the device. This can be avoided by careful design. The driver circuitry, coupling, and voltage balancing circuitry can be seen in figs. 5-3 (pulldown switch) and 5-4 (pullup switch).

The speed of the FET can give rise to a parasitic destructive

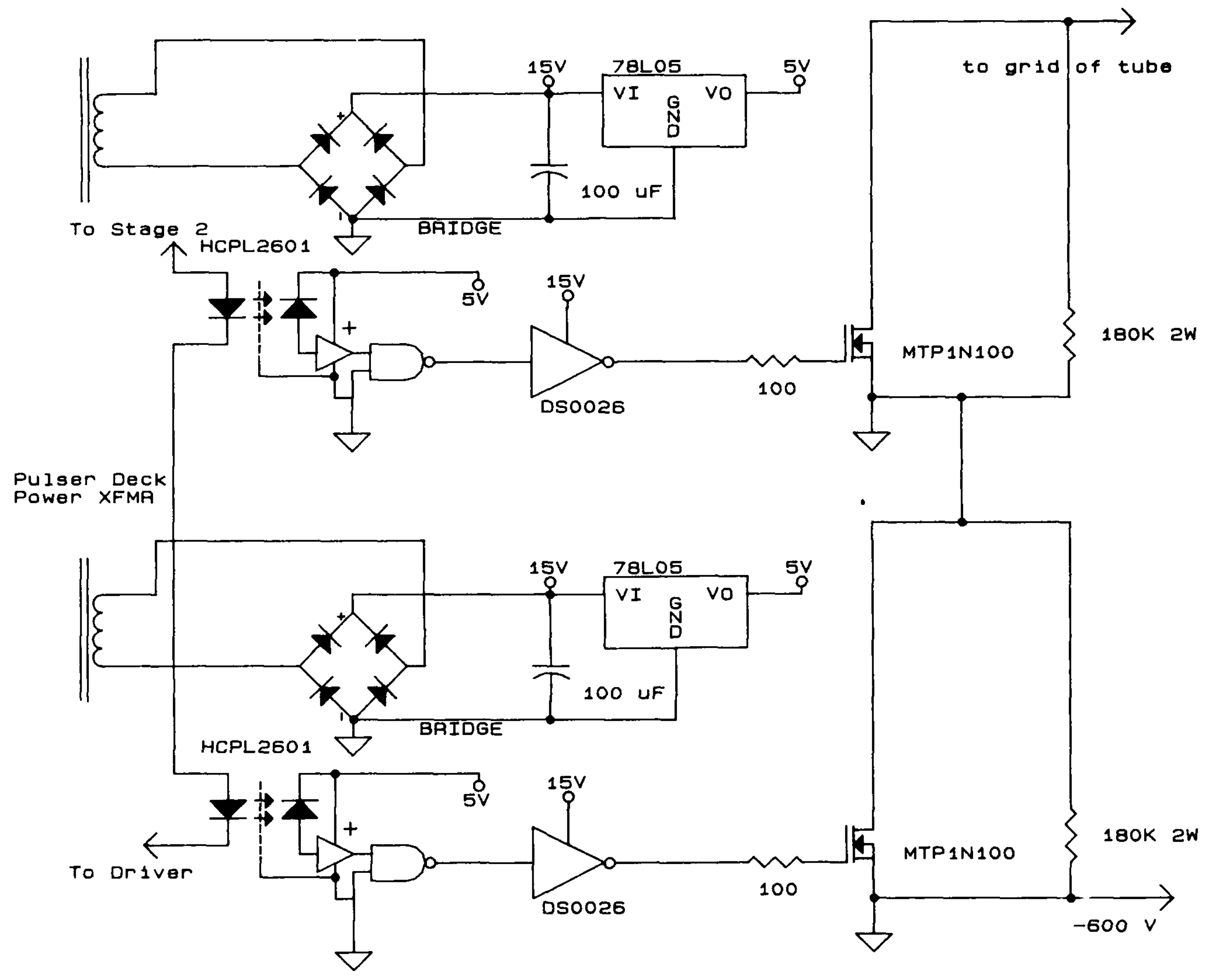


Fig. 5-3. Pulldown Switch

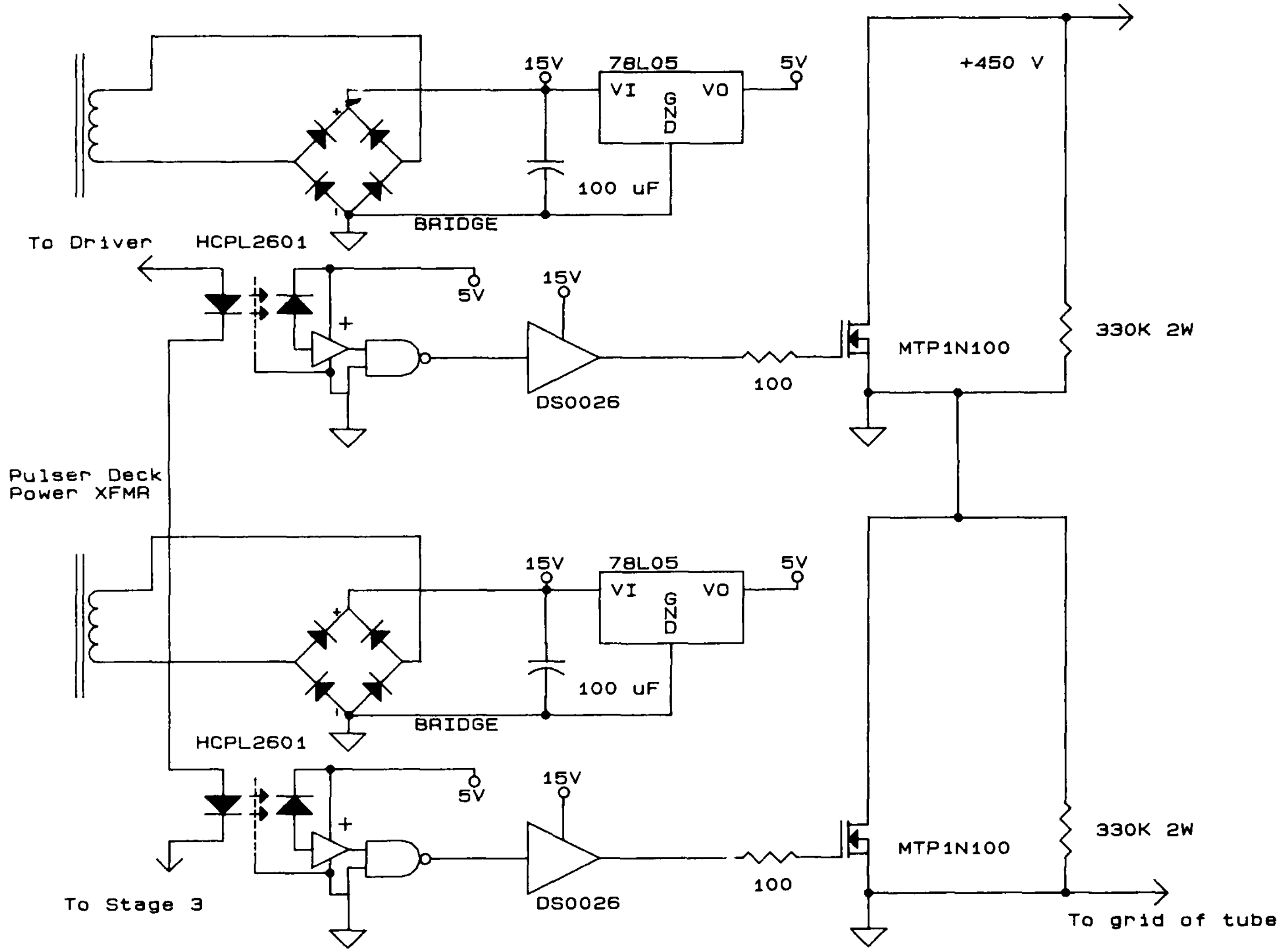


Fig. 5-4. Pullup Switch

oscillation which has been documented in the manufacturers' literature. An effective preventative is a small (100 ohm) resistor in series with the gate which effectively damps it out. It also slows the circuit down due to the RC time constant formed by the resistor and the capacitance of the gate. Better drivers and layout may reduce or eliminate the necessity of the gate damping resistor.

5.9 VOLTAGE BALANCING

A resistor voltage balancing network on each FET deck ensures voltage sharing at a small penalty in power. The leakage current of each transistor is very small and 500K resistors effectively swamp it out.

5.10 STAGE POWER

Getting power to each FET stage is a requirement of the optoisolated approach. Less than a watt is required by each stage, so a small square wave switching power supply can be used. A common transformer core can be used as long as the sections have sufficient isolation due to low interwinding capacitance and DC voltage holdoff. A line frequency transformer probably has too much interwinding capacitance to be useful. This capacitance must be driven by the modulator because it is in parallel with the TWT grid capacitance.

In the breadboard pulser a standard switching regulator was used (fig. 5-2, bottom) to drive darlington power switches. A 3 inch ferrite core was used to isolate the stages from each other and ground; this provided good coupling and a small feedback winding was adequate to regulate the switcher.

The second version of the pulser uses a quad power supply recently introduced by Burr-Brown for high isolation applications.

A transformer coupled, rather than optocoupled, approach would not have needed a power supply; the bias voltages required would have been generated by the trigger. The development work required can be substantial but the speed of the circuit can be as fast as the transformer driver circuit.

5.11 TWT DRIVE VOLTAGE

A TWT grid must be pulsed positively with respect to its cathode to allow the electron beam to form. The time spent in switching must be minimized to reduce the defocusing which occurs at low drive. The defocused beam can be intercepted by the body of the tube, and seen in the body current as "ears" on the pulse. This is more accentuated in the Raytheon tube used in the Surveillance Lab L band radar, but the S band tube suffers from

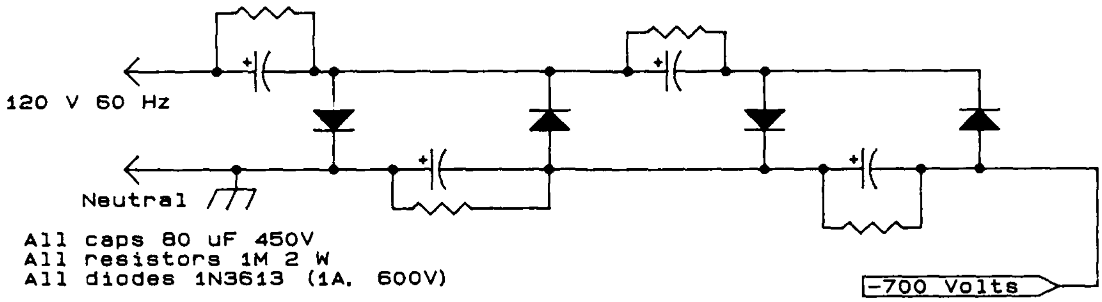
this effect somewhat. The drive voltage was therefore made adjustable only down to 100 volts to eliminate operation at zero bias. It can be increased to 500 volts by a front panel control.

Since the pulser floats at cathode potential (41 KV), the drive voltage cannot be adjusted without a means of voltage isolation from the front panel. In many transmitters this takes the form of a plastic shaft to wherever the control is located. This is preferable because of its simple construction. In WBA 2 this was difficult because of the physical layout of the transmitter, so a Teledyne 9400 voltage to frequency converter in the control logic, controlled by the front panel grid drive pot, drove a LED fiber optic link. In the pulser, an identical chip, configured as a frequency to voltage converter, reconstructed the DC signal and fed it into the regulation loop of a 500 volt switching power supply. This arrangement produced a control link which was very fast, but because of its speed was susceptible to power supply noise and component variations. The later version of the pulser used a similar circuit. Evaluation of both circuits shows that they would be inadequate for precision setting of the grid pulse levels, due to the FMing of the signal. A better solution would be to use a digital word sent periodically to an A to D converter in the pulser. This would trade speed of adjustment for increased accuracy. The circuits used, however, have been adequate for Surveillance Lab use.

The 500 volt supply used for the positive grid drive is a modified off the shelf power supply. It is a square wave switcher in which the 12 volt input is linearly regulated down, then chopped, transformed, and rectified. The output is compared with the DC command signal to develop the linear regulator voltage. Thus, to obtain a low output voltage the input voltage to the chopper must be low, perhaps below that required to sustain oscillation. A better, more efficient method would use a pulse width modulator off the 120V line. Unfortunately, it remains difficult to obtain commercial power supplies at this voltage and current. The second version of the pulser used a 60 Hz transformer followed by a linear regulator. This resulted in a heavy, inefficient design.

5.12 TWT BIAS

A radar tube spends the majority of its time with the beam off. This requires, in the case of the VTS5753, a negative bias of 600 volts. In many pulser designs, a transformer generates a stiff bias supply. Since the tube in the biased off condition does not generate any signals, ripple and noise on this supply is of no consequence as long as the tube stays within a range of bias-off voltages. Therefore, a voltage multiplier with poor ripple and regulation performance was used to generate the bias (fig. 5-5, top). The disadvantage of not being isolated from the line is of no consequence because a 60 Hz isolation transformer



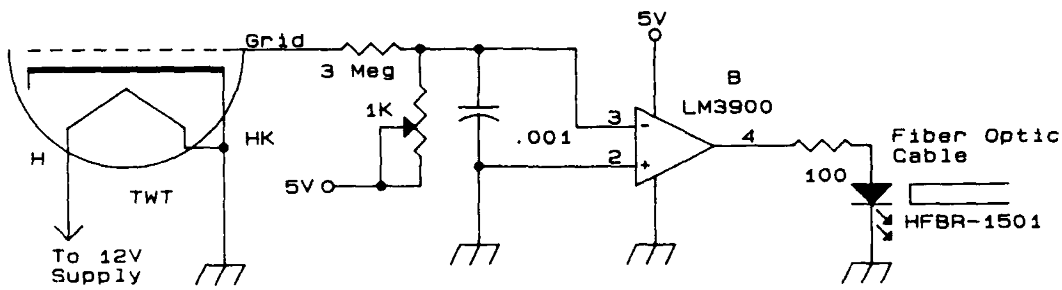


Fig. 5-5. Grid Bias Supply and Pulser Interlock

has to isolate the entire floating deck at 41 KV.

5.13 HEATER SUPPLY REQUIREMENTS

The typical TWT's cathode heater is a coil of tungsten not unlike an incandescent lamp. Its cold resistance is about a tenth of its hot resitance, but its time constant is several minutes due to the cathode mass it has to heat up. It is necessary, therefore, to limit the inrush current so that the heater is not damaged during warmup. The easiest, and most commonly used, way is inserting large amounts of inductance or transformer leakage inductance in series with the tube.

Heaters can be powered by 60 Hz AC effectively as long as regulation requirements are not strict. It is difficult to electronically regulate 60 Hz AC, but DC supplies are available with much better regulation. The S band tube is rated for DC heater operation so both transmitters use it.

An off the shelf Lambda power supply rated at 12 volts and 20 amps was used to supply both the tube and the grid pulser circuitry. The tube heater takes 11 volts at 11 amperes, so a dropping resistor makes up the difference.

Commercially available power supplies are virtually all voltage regulated rather than current regulated, although they are current limited to avoid short circuits. In the tube heater application, the desire was to regulate the current to avoid stress on the heater. A separate circuit, shown in fig. 5-6, was added to the Lambda supply to effect this function. It used the dropping resistor to sense the current and fed into the voltage regulation loop. The circuit was tested by using two 18 volt 100 watt projector bulbs as a load. The bulbs are a good simulation of the tube heater except for the time constant. The current regulator limits the output of the power supply for several minutes, during which time the voltage slowly creeps from about 4 volts to the full 12 volts. This ensures minimal heat shock stress to the tube. At about 8 volts, the rest of the pulser circuitry begins to operate. The PULSER OK interlock does not operate until the entire pulser is running.

5.14 INTERLOCK

In the case of loss of grid bias, the tube would conduct approximately 1 amp continuously. While the collector could handle this power, the body of the tube would suffer too much interception because the beam is improperly focused. If a sensor was put on the bias supply, however, it would not detect damage to the rest of the circuit. The pullup transistors could short, the pulldown transistors could open, the driver could erroneously call for too much duty cycle, the floating power supplies could fail, or a similar fault could occur which is unexpected and

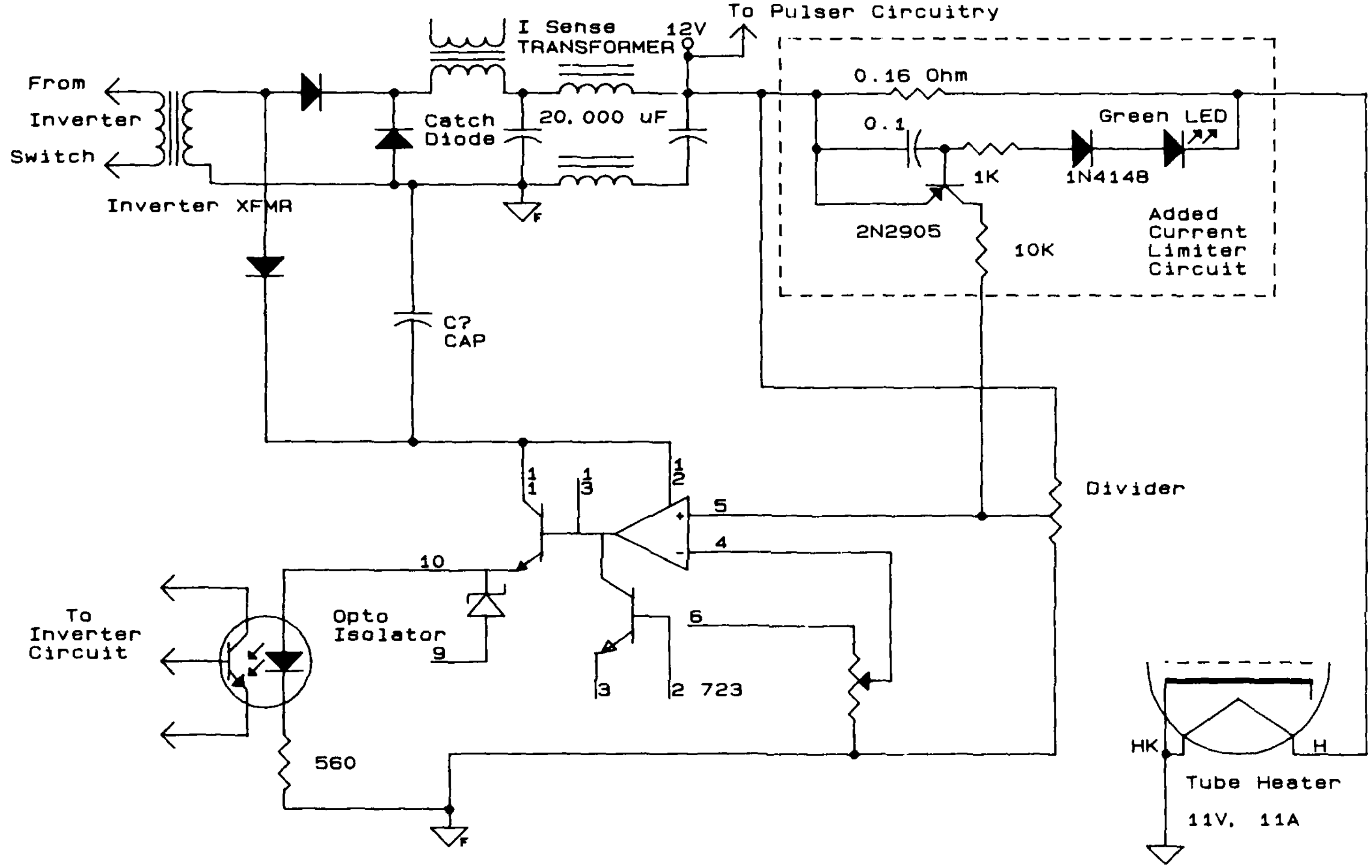


Fig. 5-6. Current Regulating Heater Supply

impossible to design for.

To preclude this, a voltage detector, shown in the bottom of fig. 5-5, was added to the output of the pulser to detect a wide range of malfunctions. It does this by attenuating and capacitive filtering the output signal, then using a Norton current differencing amplifier as a comparator to drive the interlock output signal. If the output goes above -200 volts, the interlock shuts off and high voltage and pulsing are disabled. The filter components are carefully chosen so that full positive grid bias applied for the maximum pulse width (300 microseconds for this tube) does not trip the comparator. It will trip if the positive pulse continues longer than 300 us due to improper drive or hangup of the switch transistors. In addition, if the bias supply malfunctions the pulser output will rise to zero volts, again tripping the interlock. Thus it is the effect of a pulser malfunction which is sensed, rather than the cause.

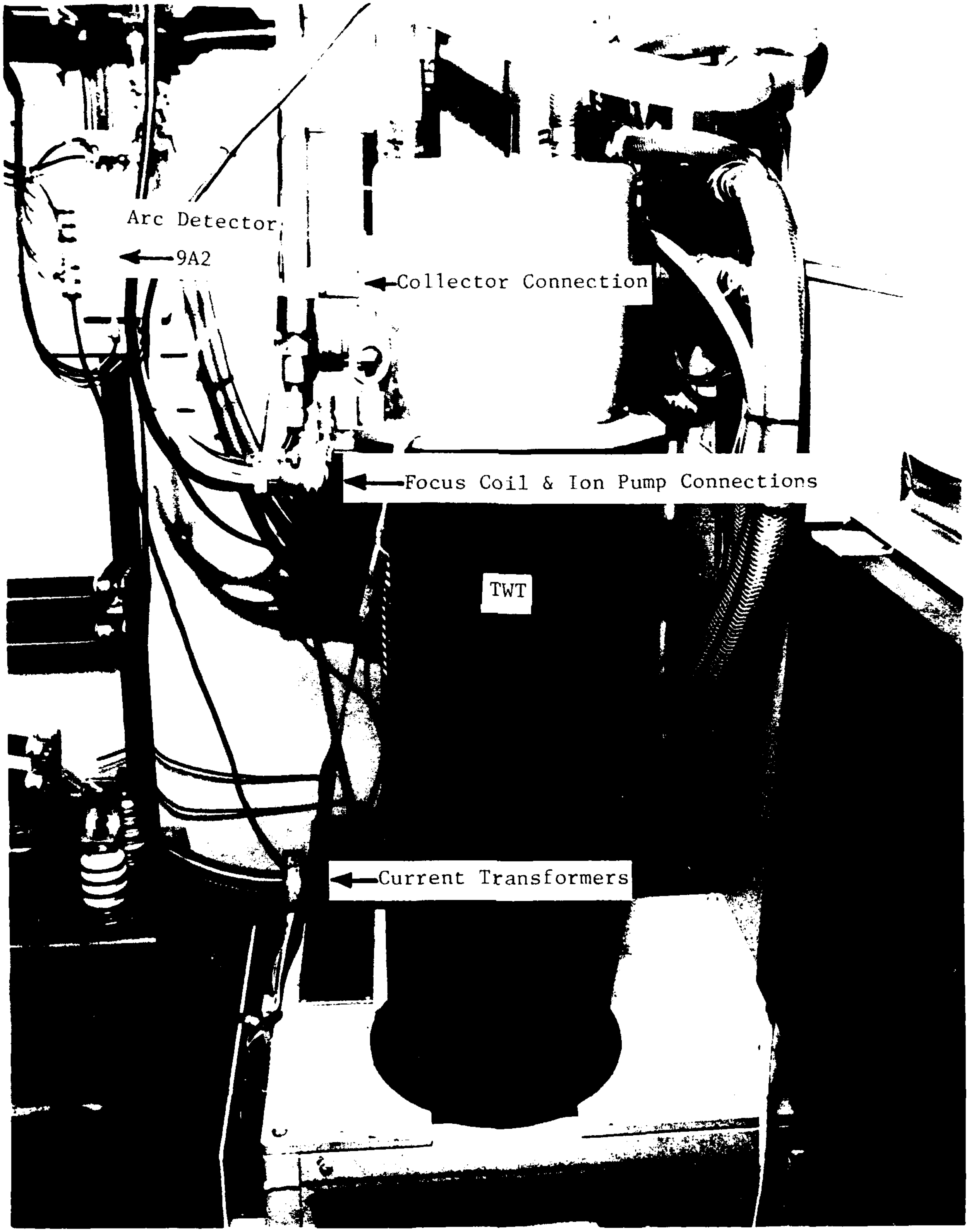


Fig. 6-1. Traveling Wave Tube

6. TRAVELING WAVE TUBE

WBA 2, like WBA 1, uses a single stage traveling wave tube as its final output (fig. 6-1), driven by a 10-20 watt traveling wave driver amplifier (left side of fig. 4-4).

6.1 VTS-5753

The Varian Associates VTS-5753 family of tubes is part of a mature family of tubes which have been produced since the early 70's. The early versions were limited in bandwidth mainly by the output window which would develop moding problems at 3.6 GHz. The rest of the tube internal circuit was sufficiently wideband to support a wider bandwidth. The wideband requirements of the Digitally Coded Radar resulted in an RADC contract to extend the bandwidth of the tube. The test results are reported in RADCTR-77-174, "Extended Bandwidth VTS-5753B1 Coupled Cavity Traveling Wave Tube". The B1 version was not mechanically interchangeable due to the output window configuration, but the window was subsequently refitted into the production tubes and they were designated the -A8 version. The wideband window was tested to 8% duty at 175 KW with normal temperatures, indicating plenty of average power capability.

Originally, WBA 1 was fitted with a transversal equalizer to improve the time sidelobe response resulting from phase ripples in the passband of the tube. Since the DCR used a wide bandwidth square wave to phase modulate the signal, the components of the signal would theoretically be of infinite bandwidth, although they were limited to the 3.1 to 3.7 GHz bandwidth of the tube. What it did to the signal was to reduce the risetime of the modulating square wave so that the phase transitions were clearly visible on an oscilloscope, whereas ideally no amplitude variations would be seen. The equalizer reduced the phase variations across a +/-10 nanosecond compressed pulse. During experimentation in the RADC Module Evaluation Lab the paired echos could be reduced as much as 40 dB with careful adjustment, which is the limit of the exciter (the Wideband FM Generator).

In most transmitted signals the bandwidth is not so great and the phase ripple requirements not as severe. The passive gain equalizer supplied with most tubes is sufficient to adjust the gain so that wide variations in power are not realized over different parts of the band. If a high resolution signal is again required, the transversal equalizer should be again refitted and readjusted for low time sidelobes.

Typically, phase variations of the tubes over frequency are very low in the lower end of the band, within about 5 degrees. At about 3.5 GHz deviation increases, and the gain and saturated power rolls off. These effects are probably related, although no remedy has been found. A tube with 170 KW output across the band

will tend to fall to approximately 100 KW at the high end due to decreasing saturated power above 3.5 GHz. This effect tends to be present in many other tubes.

6.2 SPECIFICATIONS

The following are the conditions under which the tube is allowed to operate. Listed are absolute ratings which the tube MUST be operated within; recommended operating points; typical performance; and acceptance test conditions.

Power output: (acceptance)
140 kw, 3100-3500
110 kw, 3500-3600
35 kw, 3600-3700
Typically, the power rolls off above 3500 MHz to about 75 KW at the band edge. This is for a single frequency saturated output; a wideband signal would be transmitted with normal gain at the high end.

Waveguide pressurization: 0-35 PSI (gage). Dry air, oil-pumped nitrogen or Sulfur Hexafluoride at slightly above atmospheric are all adequate.

Coolant pressure: 150 PSIA Max.

Coolant Temperature: 0-60 C. Must be above dew point of ambient air.

Coolant Flow: 16 GPM min. of 0 to 50 % mixture of technical grade Ethylene Glycol and water. Pressure drop across the tube is 75 PSI or less.

Coolant Quality:
Resistivity: 500 Kohm/cm min.
Organic matter: none
Particle size: 5 Microns max.

Pure water may be used but the tube must be protected from freezing at all times. Tube must be flushed prior to storage or shipping.

Cathode external temperature: must be maintained below 60C by passing 30 CFM of air over the fins whenever the heater is on. This is done in the transmitters by nominal 150 CFM fans.

Heater power: 10 to 12 volts; 12 amps max; surge current must be below 25 amps. These values are maintained by the heater supply. Current is limited to 15 amps which makes the warmup very gradual. A 5 minute warmup is recommended; an interlock is provided which prevents operation for 5 minutes. Actual tube values are stamped on the nameplate of each tube.

Cathode current: 17 Amps max. Nominal cathode current for each tube is on nameplate; grid pulse voltage should be adjusted to reach rated cathode current, which represents beam saturation.

Arc protection: tube current must be limited to 500 amps and crowbarred within 2 microseconds. Limiting resistors between the power supply and tube assure this current is not exceeded. Longer durations will damage the body or cathode of the tube.

Cathode to ground potential: 42 KV max. 41 nominal. 40 KV is the minimum required for pulsing. A sensor on the power supply prevents pulsing until this level is reached.

Body current:

0.4 amps w/o drive (acceptance)
0.8 amps w/o drive (maximum)
1.5 amps with RF drive (acceptance)
1.6 amps with RF drive (maximum)

Body current above maximum levels must result in pulsing shutoff within 20 microseconds, or body circuit damage could occur. The body current is sensed by the crowbar circuit to protect the body.

Grid voltage with respect to cathode:

Bias: -500 to -1500 volts, -600 nominal
Beam on: 800 volts max.; 450 nominal

Grid current:

50 ma max. (acceptance)
200 ma max. (limited by grid pulser)

This current is inherently limited by the low power capacity of the grid pulser.

Grid capacity: 100 pF, max., all other elements grounded (acceptance)

Collector voltage to ground:
-15 to 10 KV max. range (1 sec. max)
-6 KV nominal

Pulse width: 330 microseconds max.
An input pulse width detector is set to this value and results in a return to standby condition.

Duty Cycle: 10% RF, 11% beam, max.
This value is also set into the interlock circuit.

Source or load VSWR: 1:1.2 max.

Isolators are provided on both input and output to protect the tube from mismatches.

Solenoid voltage and current: 200 v and 26 amps max.

Nominal values are stamped on each tube. The critical value is the current, which is directly proportional to the magnetic field produced. Thus a current regulator is used. The voltage required to maintain the set current will creep up as the solenoid warms up.

The solenoids on early versions of these tubes are prone to shorting out at one end, which is why a floating power supply was used.

RF drive power: 20 watts max. Typical is less than 5 watts, and is on nameplate.

Ion pump: 3300 volts, 1 ma max. Ion pump should be run every 6 months in storage and continuously when operating.

Radiation: 1.5 Mr/hr max, 12in. from collector (acceptance)

Phase sensitivities, max (acceptance):

To Cathode voltage: 75 deg/KV
To grid voltage: 1.25 deg/volt
To Solenoid current: 3 deg/Percent change
To Drive power: 6 deg/dB
To collector voltage: 8 deg/KV (This value is typically unmeasurable)

Amplitude sensitivities, max (acceptance)

To Cathode voltage: 1.25 dB/KV
To grid voltage: 0.05 dB/volt
To Solenoid current: 0.3 dB/Percent change
To Drive power: 0.25/dB
To collector voltage: Unspecified (This value is typically unmeasurable)

Spurious output, beam on, RF on or off: 0 dBm/MHz max.

Spurious output, beam off: -100 dBm/MHz Max.

AM and PM noise: -80 dBc/MHz max.

7. WAVEGUIDE

Standard CPR284 aluminum waveguide is used to connect the output of the tube to the antenna. The main components of the waveguide assembly are shown in fig. 7-1. Flat rectangular flanges are used; these mate with most modern parts. A circulator on the transmitter (shown in the upper middle of fig. 7-1) serves two functions: it isolates the tube from antenna VSWR, and steers the receive signal into the receiver. The antenna reflected signal due to VSWR is of course reflected into the receiver, and a succession of limiters reduces the main bang to manageable proportions. The isolation from the tube to the receiver port is 30 dB, which is less than the typical antenna reflection. A waveguide switch permits testing at full power into a dummy load. Two forward and one reflected directional couplers are on the output waveguide line.

7.1 PHASOR COMBINING

The antenna is capable of several different polarizations using the two transmitters. In all cases the two transmitted signals are always orthogonal, which is necessary for proper isolation between transmitters. Since the antenna has horizontal and vertical polarizations, the easiest way of hooking up the transmitters is one to each polarization. The receivers are on the return ports of the circulators, and so they receive the same sense that was transmitted. Both transmitters can be pulsed independently, so a wide variety of signals is possible; the horizontal channel can be used to maintain track on a target while the vertical tests a different waveform, for instance.

The two transmitter outputs can be combined in space to form different polarizations. If they are phased 90 degrees apart, the signal becomes circularly polarized, with the sense determined by which signal leads. When they are in phase or 180 degrees out, the signal is linear but at a 45 degree inclination. With this dual linear arrangement, the circularity of the signal in space is very dependent on the accuracy of the phase and amplitude of the transmitter signals.

One transmitter can transmit circular polarized signals if a 90 degree hybrid is inserted in the line, with the output feeding the two linear antenna feeds. The waveguide runs and antenna feeds must be aligned in time and carefully fine tuned in phase, but once this is done any power fed into the hybrid is combined in space to produce circular polarization. Any distortions in the signal do not cause distortions in the rotation of the signal. A signal into the fourth port of the hybrid will produce the opposite rotational sense of the other. Thus two transmitters can be used with different timing, or if they are used with the same signal, they can produce linear polarization at double the power of one transmitter. This linear polarization can be rotated by shifting the phase of one transmitter. In this mode, the linearity of the signal in space is very dependent on the

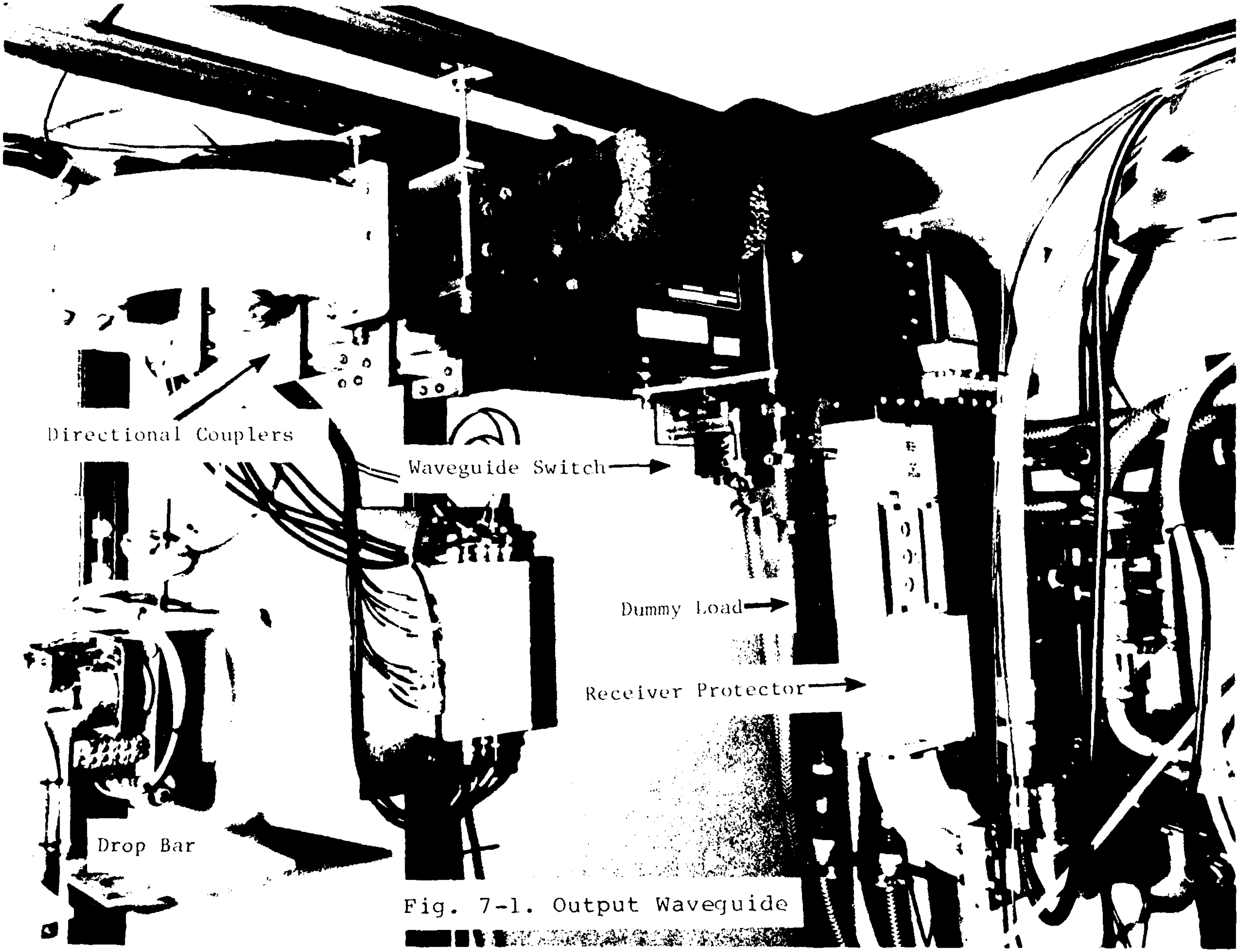


Fig. 7-1. Output Waveguide

amplitude and phase errors of the transmitted signal. The 90 degree hybrid waveguide section was designed to replace the waveguide bends at the point where the output waveguides of the transmitters come close together just above the shack. The bend sections were custom brazed to enable easy bolt-on replacement.

7.2 ARC DETECTOR

The possibility of a tube output waveguide arc is low, due to the use of an isolator on the output and the maintenance of a dry air environment in the waveguide. Still, an RF arc maintained at the output window would result in a catastrophic failure of the tube. To preclude this an arc detector is part of the first waveguide piece on the tube output. It consists of an optically triggered SCR which is roughly focused on the window of the tube. An arc is essentially a short circuit through which all the energy of the RF pulse is dumped, generating enough light to trigger the SCR. The signal generated is routed to the interlock circuits, where it inhibits pulsing (see fig. 4-14, bottom). Since the SCR latches, it must be reset by interrupting current through it. This is accomplished by shorting out the SCR with a transistor when the front panel RESET switch is pushed. The arc detector is tested by lighting a light bulb which is in proximity to the SCR. Whether this is an accurate test of the arc detector is not known.

7.3 DEHYDRATOR

The waveguide system is provided with a dry air pressurization system which maintains approximately 1/2 PSIG of dry air on the waveguide system. This level is sufficient for suppression of arcs in the waveguide up to the level of 500 KW if VSWR is 1:1. The VSWR in the antenna system is about 1.3:1; this lowers the power handling capability of the waveguide, but if dry air is maintained on it there should be no problem. The antenna system has a controlled leak at the end of the feed horn, so all the air put into the bottom end exits at the top of the antenna. This flushes water out continuously. Because of this leak, the waveguide pressure sensor in WBA 1 was disconnected, because it would not detect less than 5 PSI. The interlock channel is used instead to connect to the fault summary signal in WBA 2.

There is a dessicant at the outlet of the dehydrator, not as a drying agent but as an indicator. If the dessicant is pink, the dehydrator is not removing moisture and needs repair. The dessicant normally is blue.

8. COOLANT SYSTEM

Due to the large amounts of heat generated by the system, some components are cooled by a flowing ethylene glycol and water mixture. A purification system is provided to filter out particles in a micronic filter , and to remove other dissolved impurities in a mixed bed ionic exchange filter. The water purity should be held above 500K ohms per square. Otherwise, excessive leakage or even an arc would occur across hoses that have voltages across them, especially the collector which has 6000 volts across it. The hoses have approximate dimensions of 1 square inch in cross section and 12 inches in length. Thus the maximum leakage is about 2 milliamperes, which is a power of 12 watts per hose. Sedimentary deposits and deterioration of the hose may increase the leakage current.

8.1 HEAT EXCHANGER

The heat exchangers are shown in fig. 1-2. The white unit on the right serves WBA 2. It is a commercial unit, but differs from the WBA 1 unit to its left in several ways which make servicing and troubleshooting easier. Gauges are provided for flow, temperature, reservoir level and pressure (these had to be added to the old unit). Unions are used in places prone to repair, such as the pump and filter, instead of being brazed. Outer panels are removable instead of riveted. A bridge resistivity meter was used, rather than a neon light indicator.

A 28 volt relay controls the power to the cooler automatically from the transmitter. Cooling of the water is done by a large radiator through which ambient air is forced by a large squirrel cage fan.

During the DCR tests at the Verona Test Site, considerable difficulty was encountered during days of low ambient temperature. The ethylene glycol 50% mixture turns into a high viscosity syrup which failed to close the flow interlocks. A temperature switch was added to the fan motor to allow the coolant to warm up before the fan comes on. This eased the problem considerably, but it was still sometimes necessary to run the solenoid supply for a half hour or so to get the coolant warm enough to close the flow interlocks. On WBA 2 an adjustable thermostatic control regulates the operation of the fan to allow warmup. As the heat exchangers and piping are blocked from the full force of the wind by the building, the warm-up problem encountered in Verona is not as severe.

On the L band transmitter, a 5 gallon water heater keeps the temperature up to avoid this problem. A better solution would be to keep reservoir tanks inside the personnel compartment where possible. This could also permit utilization of the waste heat. This could be of some advantage at a radar installation which is run constantly, but the S band is not operated sufficiently often to take advantage of it.

8.2 COOLANT LOOPS

Liquid coolant is supplied to the transmitter through three coolant loops, which are valved off in parallel, interlocked, fed to their respective heat loads, and teed together on the return side. The return is through 2 inch pipe (middle of fig. 8-1) to both heat exchangers. This eliminates a second pipe run and ensures mixing of the coolant so either filter system can be used.

The coolant loops are more than adequate for cooling the transmitter, and could handle the load of a high voltage power supply if desired. A 3 GPM loop cools the waveguide load, another 3 GPM loop the isolator, and the 16 gpm loop the tube. The tube further splits the coolant into collector, solenoid, and body cooling loops. When the tube is running its full 6% duty cycle, about 75% of the beam power is converted to heat in the collector and about 5% into the body due to beam interception; when no RF drive is present, virtually all the power ends up in the collector.

Power=(Beam current)X[(beam voltage)-(collector depression)]XDuty

15 A. Beam x (42KV-6) X .06 = 32 KW

The solenoid uses 25 amps at 100 volts, or 2.5 KW.

When the first VTS5753's were built, a number of them failed due to the solenoids burning up because Varian put most of the cooling into the collector and starved the solenoid. Later versions of the tube and and rebuilt tubes have more coolant flowing through the solenoid. Another original problem is the quality of the hose used in the collector, which must withstand heat, 6000 volts, 90 PSI, 10 GPM flow, RF leakage, and even X rays. The Norton Tygon tubing originally used tends to degrade over time and has been replaced at Varian by a proprietary silicone.

9. HIGH VOLTAGE

The 41 KV and 10 KV power supplies of WBA 1 provide the cathode and depression voltages for both tubes since they are wired in parallel. This is done so that the droop will be the same when both tubes are fired at once as it was with the single tube. When only one tube transmits during a pulse the droop is half the two tube droop. The capacitor bank on WBA 2 (fig. 9-1) is identical to that on WBA 1; therefore, the amount of energy stored is doubled. This presents a problem in that the doubled energy storage must be dissipated during an arc. The time constant of the RC circuit is slower than the firing time of the crowbar so that both crowbars are fired to dissipate the energy.

9.1 CROWBAR

Electronic crowbars are provided in both transmitters to dissipate arc energy. Mercury filled ignitrons were used because of their high current capability (thousands of amperes) and fail safe characteristics (they usually fail by shorting, rather than by failing to fire). Both of these characteristics are due to the use of a liquid for the arc electrode, which makes the electrode self-replenishing and self-cleaning. The disadvantage of this is that the mercury sloshes around and can coat the walls of the tube; then it must be burned off and recondensed in the pool in the bottom of the tube. This makes it unacceptable for tactical or other applications where the ignitron is not always motionless. Sometimes firing the crowbar will splash enough mercury to cause the tube to break down at operating voltages. To minimize this problem 100 watt dissipation resistors are attached to the anode of each tube (which is grounded) and wired into the lighting circuit so that when the transmitter is used the anode is hot, which tends to boil mercury off the anode and condense it on the cooler cathode pool. Sometimes this is inadequate and the operator will have to season the tube with a 1 mA 50 KV power supply connected to the tube for several hours.

Due to environmental considerations, the use of ignitrons has been on the wane. The GL37248 used (left side of fig. 9-1) has been discontinued by the manufacturer; in fact, the manufacturer (General Electric) has gone out of the ignitron business and has closed its plant in Schenectady. There are only two domestic manufacturer/refurbishers left so the best course would be to replace the ignitrons with triggered vacuum spark gaps when the supply of ignitrons runs low. The S band transmitters use a total of two; the C band transmitter uses two in series to handle the voltage. The L band transmitter in the Surveillance Lab uses a vacuum spark gap.

The ignitron is fired by a 2500 volt, 100 amp, 8 usec pulse generated by the crowbar firing circuit, unit 9A1 (fig. 9-2). A high voltage isolated pulse transformer feeds the pulse between

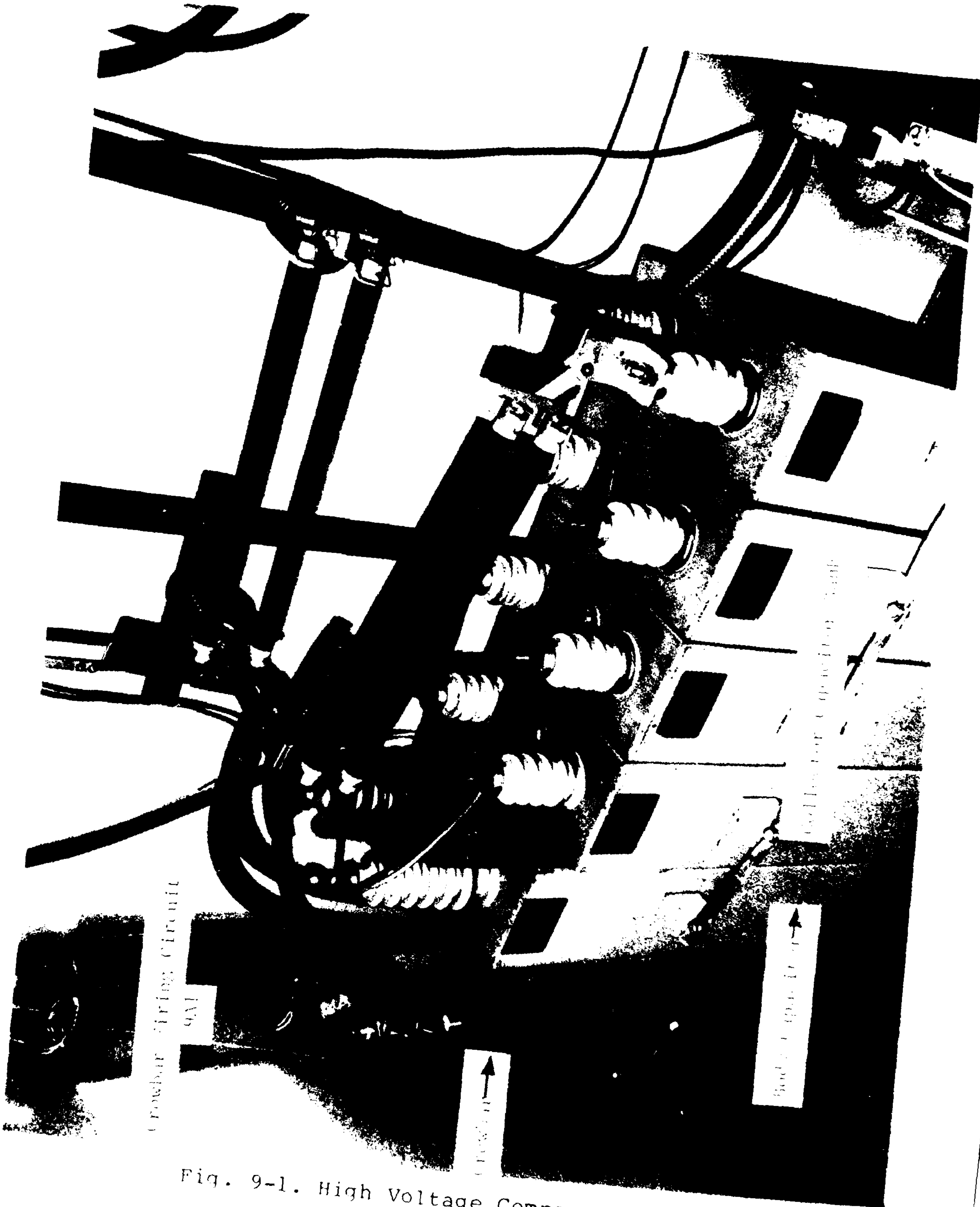


Fig. 9-1. High Voltage Components

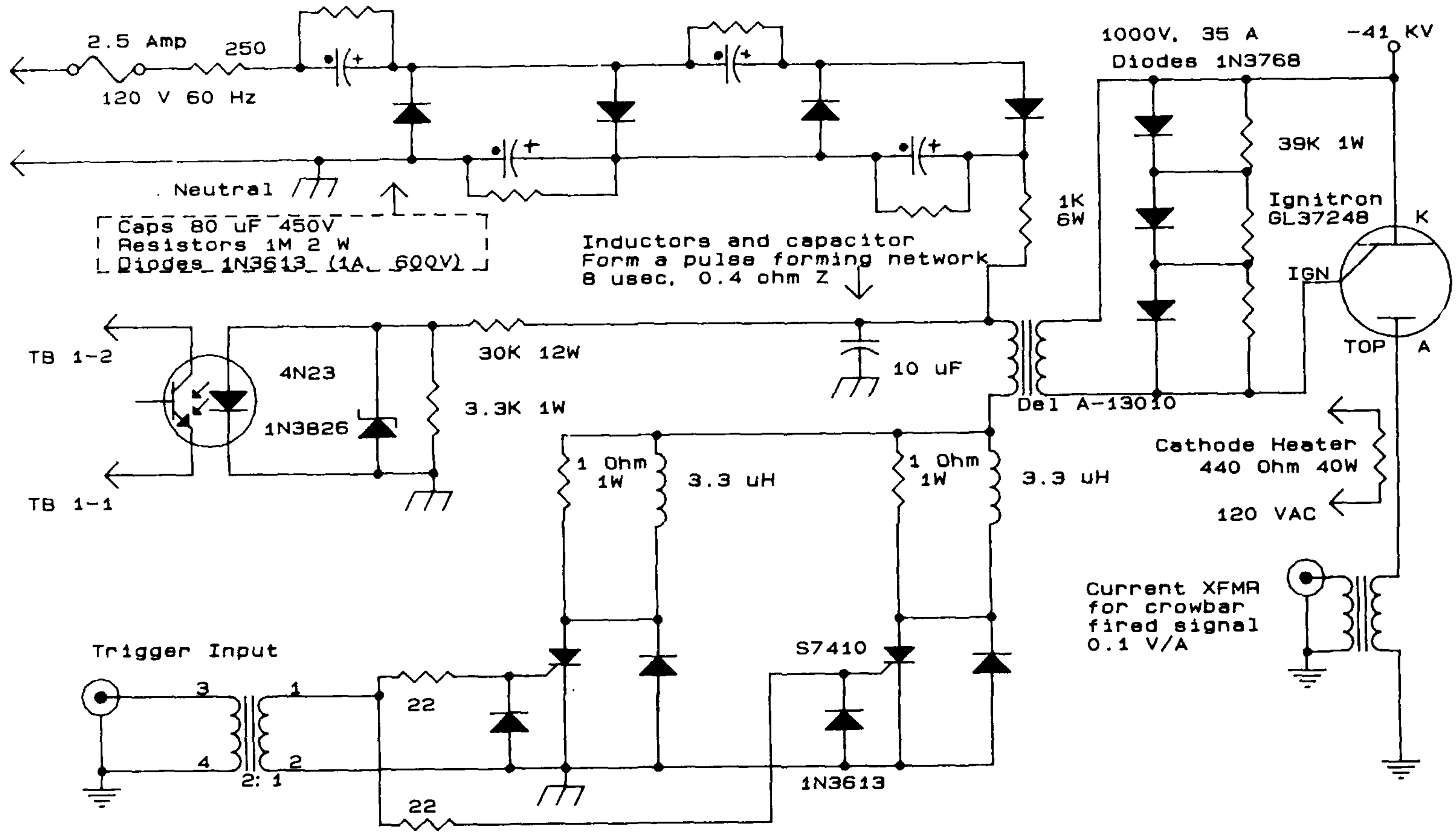


Fig. 9-2. Crowbar Firing Circuit (9A1)

the ignitor and cathode (which is at -41 KV). The pulse is generated by a thyristor firing circuit which discharges a PFN into the pulse transformer. A voltage multiplier generates 600 volts from the AC line (no power transformer is used). The 600 volts is interlocked into the HV interlock via the 4N23 optoisolator to verify that the crowbar circuit is in a state of readiness to protect the TWT. This also serves as a bleeder for the power supply.

The crowbar firing circuit is triggered by the video arc detector, unit 9A2, previously described in section 4.3. A manual crowbar test is also provided, as shown at the top of fig. 4-14.

The drop bar switch also fires the crowbar when it is de-energized. This avoids the loud noise which would be generated if the drop bar came down with the capacitor bank fully charged. The drop bar is mechanical and fail safe so that if the prime power goes off the capacitor bank is drained below lethal voltage. The solenoid of the drop bar, shown in fig. 7-1, is connected to a long arm which strikes a rectangular plate, shown at the top of fig. 9-1.

9.2 WIRING

WBA 2 is connected to the capacitor bank in WBA 1 by 150 KV rated wire. The inside conductor of this wire turned out to be very stiff and hard to bend around corners of less than 6 inch radius. Its advantages are its high voltage rating (due to graded corona preventing carbon lining around the center conductor) and its outer shield. Unfortunately it is prone to breaking of the brittle center conductor at points of attachment. A silicone insulated wire would be preferable but care would have to be taken to insure it would not radiate, since this type wire is unshielded.

9.3 FIBER OPTICS EVALUATION

In WBA 1, transformer isolation is used in the grid pulser to couple pulses to the floating deck. Two fiber optic links were used to couple signals down to ground: an interlock signal which checked the bias voltage, and a DC feedback signal for the positive grid drive. These links were homemade by RCA and consisted of IRLEDs and phototransistors coupled with "light pipes" sold by Edmund Scientific for illumination purposes. (The state of the art in optical fiber technology was not very advanced in 1978.) Over the years, all the fiber optic bundles, their spares, and replacements all suffered high voltage breakdown which shattered enough of the fiber strands to render the bundle inoperative. It was then discovered that the strands of glass were lubricated with graphite to make them slide over each other smoothly. This created a constant corona leakage which eventually caused the failure of the cable

The years after the transmitter was delivered saw a surge in fiber optic technology. Most of this was related to long distance digital data transmission, but some components and techniques have been oriented toward short distance links. In designing WBA 2, the intent was to use the most trouble free, easy to use and maintain links.

An evaluation of components was undertaken to determine which of the currently available ones were most suited for this application. The first test involved application of high voltage across a sample of cable and detection of leakage current at the grounded end thereof. The cable was then left to attract dust and moisture in ambient air for a week and tested again. This was, of course, not a definitive test like a long term life test nor a partial discharge corona inception test (for which the equipment does not exist at RADC). Samples of the following cables were tested at 100 KV over a 3 foot length, with 1 Microamp of current being the failure point:

DuPont Crofon 1040
ESKA SH 4001
Hewlett-Packard HFBR-3510
Galileo Galite 1000
GE (unmarked)
Aborn (unmarked)
AMP (unmarked)
3 Brand X unmarked cable pieces

Two of the Brand X cables, along with the glass bundles from WBA 1, had excessive leakage; the others all passed. Of all the cables tested, only the HP was specified for leakage at a certain voltage stress (10 KV/ft). The Galileo literature stresses high voltage isolation applications but has no leakage specification.

Of the leaky cables, none had any bulk resistance measureable with an ohmmeter. The leakage is apparently a corona effect between discontinuous particles in the jacket. A leakage test at high voltage is apparently the minimum requirement for determination of suitability of a cable. This is still no guarantee of a long-term performance; a partial discharge test or a long term life test would be required.

The Hewlett-Packard fiber optic components were used in WBA 2, and some Aborn components were used in WBA 1. The cables have operated successfully with no breakdown, even with no periodic cleaning. There is at least a foot of creepage path on each cable between the high voltage and ground, which is very conservative considering there is only 41 KV on them. The optoelectronic components themselves have worked satisfactorily, but the packaging and cable interconnects have not performed well. The HP packages tend to loosen up inside, resulting in an out of

alignment condition between the active area of the component and the cable. Soldering them to a circuit board rather than using sockets ameliorates this condition. The use of intermediate bulkhead connectors reduces the frequency of connector mating, which also helps.

The Aborn links use AMP square snap-in connectors which need no polishing; the cable is simply cut off square with a razor blade. This seems to result in some loss of performance due to aperture defocusing loss. The receivers use an internal LED to bias the receiver up for better sensitivity; but very little difference in sensitivity was noticed when maximum bias was applied to the LED.

Both types of links used were visible light. This greatly simplifies troubleshooting since the only way the operation of an infrared link can be verified is with a receiver or an optical pyrometer. The visible links can be unplugged and visually verified. Some loss of efficiency is a result; but over the short length of cable used (none over 5 meters) the cable attenuation is negligible. Connector mismatch is the main cause of signal loss.

Fiber optic technology can be of great advantage when engineered into a high power transmitter. Instead of using coaxial cable and coupling transformers, the cable can be run from the ground deck logic circuitry directly into the high voltage logic circuitry. The fiber is only 1 mm thick and the jacket is thick enough to make handling easy while protecting the fiber. In addition, it may be beneficial where signals must be run through areas of high transients. In a short pulse transmitter, this could be everywhere. A high degree of shielding is required near fast rise time pulses and high magnetic fields. Solid coax is the only other alternative; braided cables such as RG-214 or RG-58 all have some leakage. Solid coaxial cable was used to connect the Video Arc Monitor to the current transformers, which are surrounded by the highest voltage and current fields in the transmitter.

10. SAFETY AND OPERATION

10.1 GENERAL SAFETY PROCEDURES

Read and follow all procedures in this section BEFORE operating the equipment. All operators and maintenance personnel must be thoroughly familiar with them. There are lethal voltages present in the transmitter while it is operating and after it is turned off. AC power is still present in some parts of the equipment, and 3000 volts is present in the ion pump supply.

In the case of failure of a bleeder resistor, high voltage could be present for hours or days. Short out all high voltage points before working near them. Use the shorting stick mounted inside the TWT compartment door and leave it in place until work is completed. Use a screwdriver or clip lead to short out smaller capacitors, grasping them by the insulated handle. Under no circumstances should anyone perform service work alone.

10.2 HAZARDS

Generally, hazards are of two kinds: personnel (damage to people) and equipment (damage to equipment). This section outlines the known hazards so that the operator will be made aware of them, and as so that any subsequent modifications to the equipment will make it less dangerous, not more.

Hazards are reduced or eliminated by the following techniques:

Ionizing and non-ionizing radiation shielding.

Fault sensing circuitry which fires electronic crowbars in case of out-of-tolerance conditions.

Physical barriers to isolate hazards.

Interlocks which prevent access to the equipment while operating.

Interlocks which properly sequence the application of signals and voltages to the equipment.

AC power overload sensing devices (circuit breakers, fuses).

Thermal sensors.

Sufficient electrical grounding so that faults are diverted to ground rather than energizing nearby equipment.

Shielding of signal carrying cables to preclude false triggering and disruption of operation.

Fail safe and redundant design.

10.2.1 PERSONNEL HAZARDS

10.2.1.1 HIGH VOLTAGE SHOCK HAZARD

As mentioned above, lethal voltages are present in the transmitter even when transmitter is in the power off mode. To reduce the risk of injury, the safety requirements of MIL-STD-454E were used as a guide in the design of the equipment.

In the transmitter compartment, 41,000 volts is applied to the cathode of the tube, the grid pulser, the limiting resistors on the back wall, and the storage capacitors on the floor. This voltage is capable of flashing over several inches of air. To eliminate the possibility of personnel contact with high voltage, the transmitter is completely enclosed in a conducting, grounded cabinet. Access to the transmitter for repairs and maintenance is through a door interlocked to control the operation of the high voltage power supply. This interlock does not shut off all AC power; this allows troubleshooting to be done while the equipment is partially in operation. An interlock which shut off all power would probably be cheated to allow troubleshooting, thereby negating its effect. The voltages which remain on are either of a low enough voltage or covered to prevent injury.

Power input to the transmitter is through a circuit breaker panel on the right of fig. 10-1. The schematic of the left side of the power panel is shown in fig. 10-2.

The ion pump supply produces 3000 volts, but at a low current and through a high resistance netork which reduces injury hazard. The connector completely encloses the voltage. AC power is continuously applied to the supply to continuously clean up the tube.

The grid pulser is behind an acrylic plastic shield, but for repairs can be removed and operated independently on the workbench. In this case, -600 volts is present at the output terminal, and cannot be covered because of the tube connection design. When repairing the pulser, caution should be observed.

When operating on any piece of equipment, care should be exercised when the units are operated with the covers off to permit troubleshooting. While low voltages are not considered dangerous, there have been numerous instances of jewelry and watches bridging high current capacity circuits and causing damage and injury.

10.2.1.2 RF RADIATION HAZARD

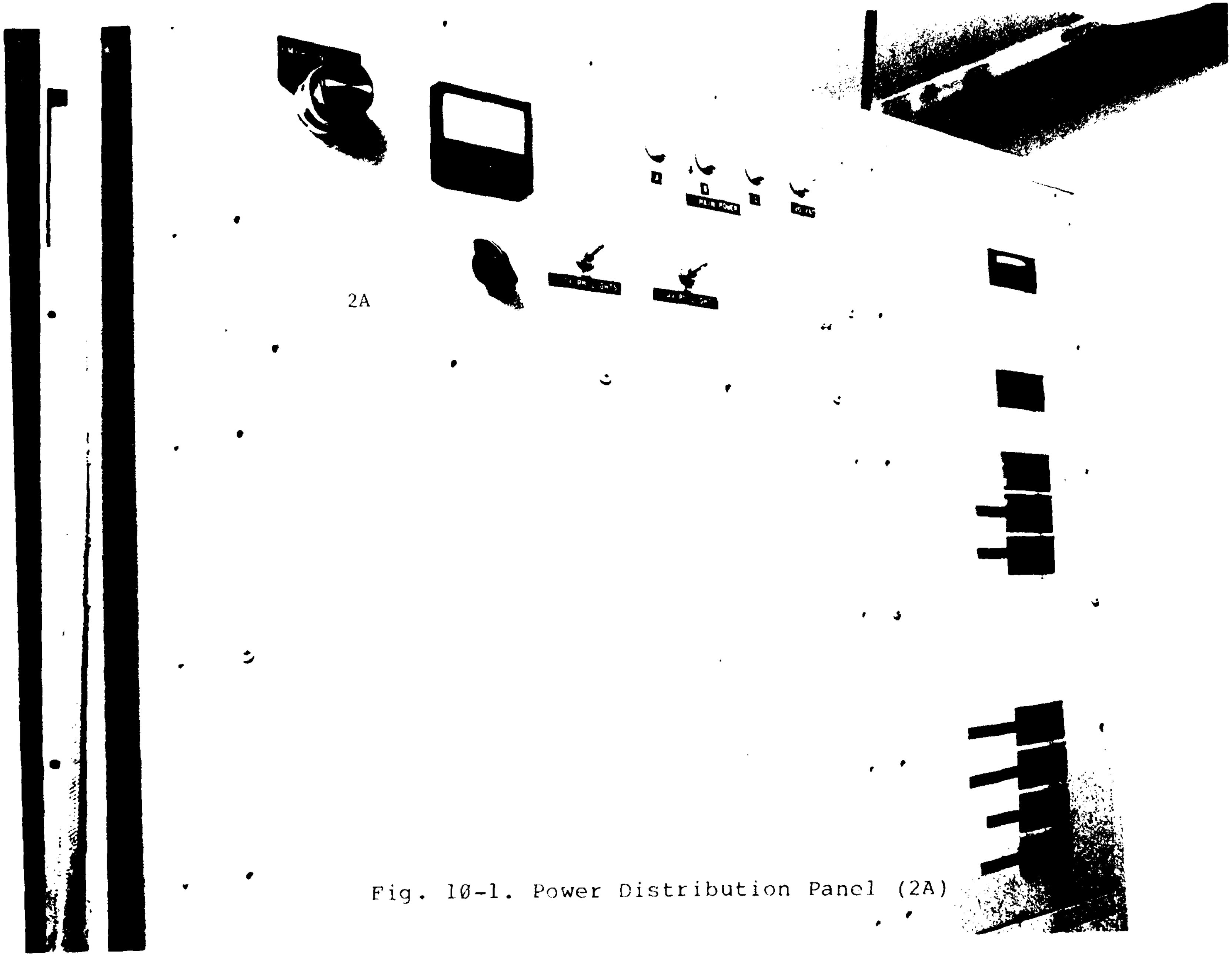


Fig. 10-1. Power Distribution Panel (2A)

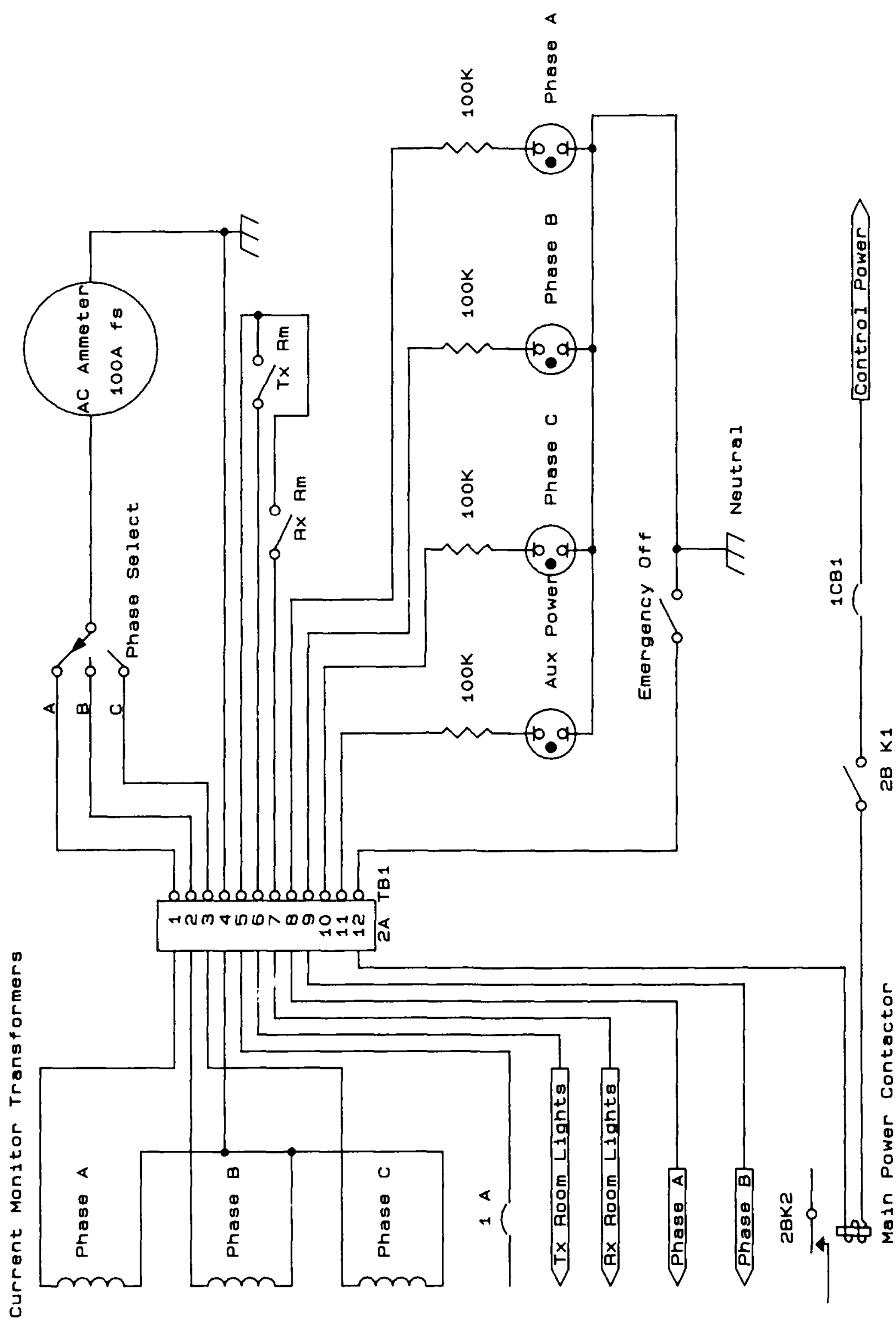


Fig. 1Ø-2. Power Distribution Panel Schematic

At the frequency of operation of this transmitter, a level of RF radiation in excess of 10 milliwatts per square centimeter is not allowed. When the waveguide is properly sealed, gaskets reduce the power leaked out by over 70 dB. Thus the total radiated leakage is less than 1 mW in the transmitter compartment. This is further attenuated by the metal wall isolating the personnel compartment from the transmitter compartment.

The S-280 type shelter the transmitter was built in was designed to further reduce RF transmission. No holes should be cut into the shelter which could couple RF energy in or out.

Since the transmitter radiates from the antenna, personnel should either stay in the shelter or in building 106 when the radar is in operation to reduce the possibility of an antenna sidelobe causing a dosage above the recommended level. In no case should any personnel be on the top level of the antenna without shutting off the transmitter and the interlock located on the base of the antenna pedestal.

10.2.1.3 IONIZING RADIATION

The 41 KV used in the beam of the tube generates large amounts of X rays which can cause permanent injury or death. The tube has a metal shield covering the collector end which reduces X rays to less than 2.5 milliroentgen per hour. This is further reduced to a harmless level by the metal shielding in the compartment. In addition, the greatest amount of residual X rays is radiated vertically along the axis of the tube out the top of the transmitter. Do not operate the tube without the collector cap in place.

10.2.1.4 THERMAL BURNS

The four surge limiting resistors on the back wall, located just above the capacitor bank in fig. 9-1, carry the full beam current of the tube and can get hot. Also, the ignitron heater resistor on its top is designed to keep the ignitron hot. Care should be taken when touching these items. Also, during malfunctions, components can overload and generate high temperatures.

10.2.1.5 MECHANICAL HAZARDS

Care should be taken in lifting the tube solenoid power supply since its weight exceeds 300 pounds. Likewise, the TWT is approximatelly the same weight, with the added problem that it is very fragile, and the cathode end on the bottom must not be jarred or have the tube rest on it. A crane is provided for lifting the tube; do not attempt to lift it.

Injury to people in the transmitter could occur due to the low head clearances at the door frames and under the waveguide. These low clearances are marked with hazard tape.

10.2.1.6 POISON

The Ethylene Glycol used in the coolant system is toxic when ingested, although not as toxic as car antifreeze which has rust inhibitors.

The mineral oil used in the high voltage transformers, capacitors, and voltage divider is non-PCB. Do not use PCB oil when refilling these items.

The receiver protector uses a radioactive gas sealed in a hermetic package. Do not attempt repair; return it to Varian Associates, the manufacturer.

10.2.2 EQUIPMENT HAZARDS

10.2.2.1 HIGH VOLTAGE FAULTS

The high voltages used in the transmitter are suseptible to arcing and flashover. Although this problem has been minimized by generous design margins and quality craftmanship, arcs may be created by anomalies such as high humidity or damage. They will typically start at a small point at which an electric field concentration will create a phenomenon known as corona. This can be seen in total darkness as a violet glow emanating from the corona point. If the corona is severe enough, it will increase in current until an ionized air path to ground causes it to conduct large currents. Since the amount of energy stored in the caoacitor bank is quite large, this can result in the sudden discharge of thousands of amps in microseconds. This effect releases energy explosively and can cause significant damage. It is also very loud.

High voltage arcs can occur inside the TWT with disastrous consequences to the delicate cathode structure. To eliminate this possibility, the fault logic continuously monitors tube ground (Body) currents and fires the electronic crowbar in a few microseconds, thus limiting arc damage. The limiting resistors between the tube and the capacitor bank limit these fault currents to a safe value.

It is normal for a new TWT to experience a high arc rate in the first few hours of operation due to surface irregularities on the gun surface which form field emission points which rapidly lead to breakdown. Sometimes, after extended service, a small piece of detritus possibly formed by an arc will precipitate another arc. In these cases the tube can be "conditioned" or

'seasoned' by putting a higher value surge limiting resistor in place of the 50 Ohms normally used. A 20 K resistor has been provided in the transmitter spares for this purpose. The resistor reduces arc current to a value which cannot further damage the tube surface but will burn away field emission points which are harmlessly deposited inside the tube somewhere or sucked into the ion pump.

The ignitron crowbar is much more prone to arcing because of its liquid nature of the mercury pool inside. This can get splashed onto the inside cylindrical walls of the ignitron, causing low breakdown voltages. This problem is treated in the same way as the tube conditioning. However, it may be advantageous to connect an external small power supply (50 KV) to condition the Ignitron, as it could take several hours to get all the mercury back down in the bottom where it belongs. In order to limit the current through the ignitron and therefore minimize splashing of mercury on the walls of the tube again, use a 2 megohm high voltage resistor in series with the power supply.

10.2.2.2 OVERHEATING

Due to the high power dissipated in the tube, solenoid, and waveguide, these components are protected by an Ethylene Glycol and water coolant system. In the event of coolant flow failure, interlocks automatically shut off the high voltage and the solenoid supply. These interlocks may be bypassed for maintenance purposes, but caution is advised, since the solenoid can be inadvertently burned up in a few minutes with no cooling.

A thermostatic overtemperature sensor is provided to also cut off high voltage power supply operation. The switch is adjustable from 70 to 140 degrees F. A good operating point is 110. This will ensure high reliability of the transmitter components which are not water cooled.

10.2.2.3 ELECTRICAL FAULTS

All AC input power into the transmitter is provided with circuit breakers with both thermal and magnetic trips. These should not open under normal currents. If a breaker trips, a low impedance exists on its load side which must be remedied by maintenance personnel before resuming operation.

10.2.2.4 EXPLOSION

The oil used in the capacitors has a very high flash point, but the amount of energy stored in them could ignite the oil. This risk is minimized by careful design which seals the capacitors and self-healing foils which limit arc current. It has happened that an arc at a bushing on the output of the high voltage power supply flashed over and the resulting explosion

(similar to a lightning discharge) destroyed the bushing. Regular cleaning and inspection of insulated items reduces this kind of problem.

10.3 OPERATION

DANGER: DEADLY VOLTAGE IS PRESENT IN THIS EQUIPMENT. DO NOT TOUCH IF YOU DON'T KNOW WHAT YOU'RE DOING!

10.3.1 TURN ON PROCEDURE

10.3.1.1. Check the following items:

Shorting hooks are stored in their clips; All tools, cables, and extranea are removed from transmitter compartments.

Close door to transmitter compartments. Leave lights on in WBA 1 (runs ion pump and crowbar heater).

Air conditioner fan turned on (unless transmitter is really cold)

Waveguide pressurizer is putting 0.5 PSI of dry air into waveguide

10.3.1.2. Turn prime power on in both transmitters by pushing both PRIME POWER ON buttons. Turn on control power circuit breaker in WBA 2 if Control Power LED is not lit (located in unit 1B, fig. 2-1). If main power relay in WBA 1 does not turn on within 1 second, shut off solenoid supply and try again. Verify that both heat exchangers come on. Check for gross coolant leaks. The heat exchanger in WBA 2 may be turned off by flipping the Heat Exchanger Enable switch in the back of the logic. This allows the transmitter to warm up quicker in cold weather without circulating coolant.

Turn on everything else required, such as the driver amplifiers, scopes, computer interfaces, power meters, etc. Turn on solenoid rrent and adjust to 25 amps. These drift terribly so they will have to be readjusted periodically as they warm up.

Check trigger pulses for width less than 300 microseconds, duty less than 6%. Turn on air conditioner to circulate air.

10.3.1.3. If the 5 minute time delay is up, check to see that all interlock lamps are lit. Turn high voltage on (from either transmitter) and verify all voltages are normal.

10.3.1.4. Turn on pulsing in transmitter(s) being run. Verify normal beam current. Turn RF on in driver amps and check power output.

10.3.2 PERIODIC CHECKS DURING OPERATION:

ion pump current under 10	microamps
Reflected power	Solenoid Current
beam current waveform	Temperature
Abnormal odors & sounds	Normal meter readings

10.3.3 TURN OFF PROCEDURE

Push HV OFF button from either transmitter (pulsing will cease automatically). Push Crowbar / Protection Test button to discharge capacitors.

Turn off solenoid supplies, driver amps, and test equipment.

Annotate operating log, noting all discrepancies and satisfactory operation. Let coolant circulate a few minutes to avoid buildup of heat in the tube.

Turn off prime power in both transmitters. Control power can be turned off in WBA 2.

Set heating or cooling units to standby. Transmitters must be kept above dew point at all times to avoid corrosion and condensation.

Shut off lights. Leave inner doors ajar and shelter doors closed.

11. MAINTENANCE AND TROUBLESHOOTING

This section describes periodic maintenance, operational checks, and troubleshooting. The operator should be fully cognizant of the operating routine before attempting repair. In addition, the sections of this report (or the manual on WBA 1) dealing with the suspected subsystem should be thoroughly understood before tackling a problem. The operational checks are intended to be used to verify operation as designed in order to isolate the problem. The sections below also contain additional hints for troubleshooting.

> NOTE: The schematics in this report are for illustration of the technology ONLY. For maintenance, use only the updated version of schematics kept by OCTS personnel on a CAD system (OrCad SDT III).

11.1 TROUBLESHOOTING METHODS

No special tools are required for maintenance of the equipment other than common electronic test equipment. A logic probe is more convenient to use than an oscilloscope or voltmeter for observing logic levels in the interlock chain, which is unclocked and generally at a DC level. Probably the best way to determine and prevent malfunctions before they turn into catastrophic failures and damage the equipment is for the operator to be aware of the normal operation of the transmitter so he or she can sense abnormal operation.

The smells of transformer oil, dry transformer varnish, resistors, plastics, fluorescent lamp ballast, paint, dust, and ozone are all different and will help in location of a problem. The sound of the various components can provide clues also; the main power supply generates a distinctive noise which is readily distinguished when it differs even slightly. A corona point will generate a small amount of hissing or ticking; the actual point can be traced by visual observation with the lights off. Several minutes may be necessary to adjust the eyes so that a corona becomes visible (be extremely careful around the high voltage).

Since a high power transmitter combines fast risetime pulses, high voltage, and high ambient noise with fast logic exhibiting non-clocked, non-repetitive signals, it can be difficult to track down noise glitches which trip out the protective logic. It may be an actual malfunction such as an intermittent arc which trips out the body current sensor; or it could be an inadvertent noise pickup on one of the many interlock or control lines. The malfunction may manifest itself for only a few nanoseconds, then disappear. One good way to isolate these problems is a digital oscilloscope, which can be set to catch the glitch on a suspected line and record it. Another is to temporarily damp out the glitch with a bypass capacitor to ground

(such as 0.01 uF), thus slowing the response of the circuit.

11.2 PERIODIC MAINTENANCE

No periodic maintenance of the electronics of WBA 2 is required. Maintenance should be initiated when operational checks of the equipment indicate a malfunction. The nonelectronic functions of the transmitter should be checked at least monthly. These include:

Ethylene Glycol concentration (should be 50%)
Liquid level in the reserve tank
Leaks, especially at connectors and seals
Hose condition and tightness
Resistivity of coolant (500K min.)
Operation of fans (ventilation, driver amp, tube cathode)
Fire extinguisher charge
Replacement of burned out panel and illumination lamps
Weather damage
Dehydrator (Dessicant must be blue)

11.3 OPERATIONAL CHECKS and TROUBLESHOOTING

Operation of the functions of the transmitter can be checked as a part of its normal operation. In case of a question of proper operation, the following operational checks can be used to isolate the failure.

11.3.1 VIDEO ARC MONITOR (9A2):

Test by using a pulse generator to simulate the signals generated by the current transformers. The beam current transformer has a 0.1 volt per amp sensitivity into a 50 ohm load. It is terminated in the arc monitor by a 50 ohm resistor. Therefore the 15 amp nominal beam current generates a 1.5 volt signal, and anything above this is considered to be an arc. A 2 volt pulse of more than 100 nsec duration should trip out the sensor, firing the crowbar, lighting the front panel fault summary and beam arc lights, and preventing high voltage power supply operation. To check the transformer run a parallel cable to the front panel and compare it with the other current transformer. To calibrate these transformers a high current pulse generator is required. An HP 214 can be used by looping a number of turns of wire from its output around the transformer core and loading it with 50 Ohms. The transformer output can then be compared with the voltage on the resistor.

11.3.2 BODY CURRENT MONITOR:

This circuit monitors all current from the -41 KV to ground. These include normal body current, abnormal body current due to tube defocusing, body arcs, and any breakdown between the high

voltage and ground. The body current should not rise above 1.5 A. The current transformer is a 1 volt per amp unit rather than a 0.1 volt per amp because the body current is much smaller than the beam current. This sensitivity is into a 1 megohm load; but it is terminated in the arc monitor by a 50 ohm resistor, which reduces its sensitivity by 50%. Therefore the 1.5 amp maximum beam current should generate a 0.75 volt signal, and anything above this is considered to be an arc. A 1 volt pulse of more than 100 nsec duration should trip out the sensor, firing the crowbar, lighting the front panel fault summary and body arc lights, and preventing high voltage power supply operation.

11.3.3 FLOW INTERLOCKS

These may be checked as part of normal transmitter operation. When the power is first turned on, the three flow lights will be off until the pump builds up pressure, then they will extinguish. The flow can be checked at the heat exchanger. To calibrate the flow sensors, run the transmitter until the coolant is at operating temperature (about 30C), then shut off two of the three loops. The remaining loop can be adjusted by closing the valves at the heat exchanger and manifold until the proper flow and pressure is maintained. Then turn the adjusting screw on the flow interlock until the interlock LED goes out. This procedure can be repeated for the other two coolant loops. Proper flow must be maintained in the tube when the solenoid is energised, and the collector and body must be properly cooled when the tube is operating. The waveguide will tell you when it gets hot; it will start to smell like burnt paint.

11.3.4 EMERGENCY OFF

The emergency off button (top left in fig. 10-4) should be checked occasionally by verifying that transmitter AC power turn on is inhibited when it is pushed in. Do not test it with the transmitter running unless there is a bona fide emergency.

11.3.5 CROWBAR TEST

Test the crowbar by pushing the crowbar fire button on the front panel. This is usually done as part of a normal turn off procedure. The crowbar may not fire below 25 KV on its anode; this is normal. If full voltage cannot be reached because the ignitron self-fires, refer to the crowbar section in the high voltage section of this report for the seasoning procedure.

If there is any doubt about the ability of the crowbar circuitry to prevent damage to the tube, the speed of the crowbar may be tested by doing a foil test as outlined in the manual for WBA 1. This test will show you exactly how much damage a metal surface will undergo when struck by an arc.

11.3.6 ARC DETECTOR TEST

The optical arc detector looks at the output window of the tube and shuts off pulsing in the event of an arc. To test, push the arc detector test button located on the top section of the rear of the logic chassis (this must be done with high voltage off). A small incandescent lamp in the detector should shine on the detector's LASCR surface, firing it and lighting the front panel LED and the summary fault light. Depress the reset button; this will saturate a transistor connected across the LASCR, commutating it. When the reset button is released, the arc detector fault should be cleared.

11.3.7 PULSER INTERLOCK

When the transmitter is turned on, the pulser begins to heat up the tube cathode. Within a few minutes, the current limited power supply in the pulser has reached about 8 volts and the rest of the circuits will start to operate. At this point a continuous fiber optic signal will be sent to the interlock logic which starts the 5 minute time delay. The time delay can be bypassed by a back panel switch for testing purposes. If the fiber optic signal is interrupted, even for 100 nanoseconds, the high voltage is inhibited and the 5 minute time delay begins anew. In case of problems with this circuit, ensure the red light signal is getting through the F-O cable, then look for small noiselike pulses on the output of the fiber optic receiver. This would indicate a problem in the pulser which intermittently trips put the interlock. The Pulser ON lamp does not have the response time necessary to permit visible indication of a small dropout in the interlock.

11.3.8 INPUT PULSE FAULT

Occasionally, through software, hardware or operator error, the trigger pulse sent to the transmitter would improperly overload the tube with possibly damaging effects. To preclude this a circuit checks for proper pulse width and duty cycle. If one of the pulse fault lights come on, check the input pulse with an oscilloscope. It should conform to TTL norms, with pulses less than 300 microseconds long and less than 6% duty. Both these limits are adjustable: the pots on the respective circuit can be adjusted while feeding in the trip-out sized signal.

11.3.9 GRID PULSER

Operation of some of the functions of the grid pulser can be verified in the transmitter. The positive drive voltage should vary in accord with the setting of the transmitter front panel control. The heater current should limit at less than 15 amps, lowering to about 11 amps as the tube heats up. The voltage should start at about 4 volts and rise to 11. At approximately 8

volts the rest of the circuitry should start to operate, and the grid pulser light should operate.

The grid pulser was designed to be easily removable so that it could be maintained on a workbench rather than in situ. The AC line cord socket on the back, which normally plugs into the isolation transformer in back of the tube stand, can be plugged into a standard line cord. Note, however, that the AC neutral is grounded to the chassis. With the pulser plugged in, use a voltmeter to verify that the case of the pulser is at ground potential.

The tube heater load can be effectively simulated by using two 100 watt 18 volt microfiche reader lamps in parallel. They will exhibit the same warmup curve as the tube, but much faster (about 1 second). When the pulser is plugged in, bias voltage (-600 V) should be present at the tube grid terminal. The trigger pulse can be sent to the pulser by using a transmitter LED assembly fed by a 5 volt pulse generator (a 200 ohm limiting resistor should be used). The pulse sent down the light pipe should be present at the grid terminal of the pulser, amplified to approximately 450 volts.

11.3.10 TUBE

Continued faults, crowbars, or other malfunctions may lead to the hypothesis of a damaged or failing Traveling Wave Tube.

SYMPTOM	POSSIBLE CAUSE	TEST
Body faults	Solenoid supply malfunction	Check output
	Solenoid short (or partial)	Check power supply, resistance
Low gain	Driver	Check output at tube
	High voltage too low or high	Check in WBA 1
	Low grid drive	Check pos. grid drive
	heater shorted	Check volts & amps
Ion pump current	Gas	
Beam overcurrent	Tube arc	Return to vendor for analysis/repair
Continuous conduction	Grid damage	Test pulser Hipot grid

12. RECOMMENDATIONS FOR FURTHER RESEARCH

During the course of building this transmitter, a number of components on the "wish list" were never found. Also, some short cuts were regrettably taken to save time which should be corrected. Furthermore, the inevitable onward course of technology presents opportunities for modernization. Thus this section delineates these possible improvements which are recommended as part of the operation and maintenance efforts of the Surveillance Laboratory.

12.1 MODULATOR SWITCHES

High voltage fast risetime switches for grid pulsers are desired for more accurate, lower jitter pulses. The most promising device for this application is the Static Induction Transistor, which is similar to the tube triode in both physical layout of conduction channel and I-V characteristics. The main advantage of the SIT is high voltage standoff capability which would make it possible to hold off the voltages necessary in a grid pulser with only one device. Thus the voltage balancing circuitry and multiple stages used in WBA 2 would be unnecessary.

12.2 SHIELDING

As shown in the report on the arc sensor circuitry (RADC TR-84-77), noise pickup can be a severe problem in high power transmitters. Conventional card cages for digital logic are simply not designed for this environment. They are constructed with large access holes for cooling and cabling. The lesson learned from the above mentioned report and experience with chasing glitches in WBA 2 is that the digital logic should be totally enclosed in a Faraday shield as a minimum. The problem of maintainability, cooling, and availability of such a logic cage remains to be answered. Ideally, the logic should be nested so that it can be accessed during transmitter operation for debugging purposes. Also, the controls should be integrated into the cabinet so long cable runs which could pick up noise are eliminated. A Tempest-shielded Eurocard type enclosure would seem to be ideal.

12.3 FIBER OPTICS

Photonic components with better rise times would improve the performance of the fiber optic links. Standardization of fiber optic connectors is a need which has not receded over the years.

12.4 CROWBARS

The mercury Ignitrons should be replaced with vacuum spark gaps. Some method of determining the operational status of a spark gap needs to be determined, because they lack the fail-safe characteristic of the Ignitrons.

12.5 ARC DETECTOR

There apparently is no literature existing on the amount of light generated by a waveguide arc. The arc detectors used are very slow, and a modern replacement is overdue. They should be small enough that they could be used in systems which are not presently using them, such as high power ECM transmitters.

12.6 TRAVELING WAVE TUBE

Tubes built by Hughes Aircraft typically use an anode for quenching body arcs, which can reduce or eliminate the need for a crowbar and increase reliability greatly. Unfortunately, the available Hughes S band tubes do not directly replace the Varian VTS-5753 because of a lower mu gun and lower perveance, which would require higher beam voltage and grid swing than is available. If a replacement tube is required in the future, this should be considered.

An additional consideration if tube replacement is contemplated is the use of a wrapped-on solenoid. One of the advantages are lighter weight, since the solenoid can be tightly wound directly around the beam tube and not need slip-on clearance for the gun. The gun structure is therefore not limited by the solenoid hole and can be properly designed for optimum voltage standoff. The disadvantage is that the solenoid must be carefully wound so that the magnetic field is exactly positioned for minimum body interception. An optimal focusing adjustment technique for a wrapped-on solenoid has not been the subject of research.

12.7 INSTRUMENTATION

Instrumentation for both transmitters could be upgraded and expanded. Peak reading beam and body current meters would be useful. A better way of setting and reading grid pulse voltage would be desirable. A general cleaning up after years of modifications is advisable.

12.8 HIGH VOLTAGE POWER SUPPLY

High power switching power supply technology has matured considerably since WBA 1 was built. A second set of HV power supplies, for beam and collector depression, could be added in parallel both to get increased average power from the radar and to achieve redundancy. It may even be time to consider replacement of the original power supply. It was an experimental version; and while a number of improvements and modifications have been made, components and topologies have advanced over these ten years and a complete redesign is advisable.

12.9 HIGH STABILITY

The transmitter was not designed for a high stability.

However, the recently completed Advanced Tactical Transmitter by Westinghouse demonstrates that pulse to pulse stability of 50 to 70 dB is achievable. The additional componentry to achieve similar stability levels in the S band transmitters could be added if needed.

The body regulator is the main source of instability in the transmitter due to phase pushing in the tube. Pushing is a direct result of the basic operation of the tube; the tube is many wavelengths long because of the slow wave structure, and variations in the voltage from the beam to the body change the synchronism (i.e., phase) of the space charge to the slow wave. Thus the limiting factor in MTI performance is generally the accuracy of the body regulator. (The collector regulator, while it must handle more power, is much less a contributor to phase pushing; moreover, the contribution of the collector to instability it may theoretically be eliminated by careful tube design.) In the S band transmitters, a ceramic, water-cooled tetrode and a 10 KV inverter supply the collector depression voltage and body regulation.

12.10 DRIVER AMPLIFIER

The ten watt driver amplifiers are octave bandwidth, which generates an excessive amount of noise over the restricted bandwidth of the radar. Another problem is the switching power supplies in them which generate unacceptable levels of high frequency ripple in the RF, thereby modulating the signal right where target doppler is located. It must be noted that each amplifier is of similar complexity as the transmitter itself. The TWT amplifiers could be replaced with solid state amplifiers. It must be mentioned, however, that experience with commercial solid state amplifiers does not portend optimistically for their reliability, performance, cost, or efficiency.

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